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WATER BALANCE RELATIONSHIPS IN THE JOHNSTONE LAKE BASIN OF SOUTHERN SASKATCHEWAN

by

© WEN CHIAN LIN

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Water Balance Relationships in the Johnstone Lake Basin of Southern Saskatchewan", submitted by Wen Chian Lin in partial fulfilment of the requirements for the degree of Master of Science.

Date. 4th August 1970.

ABSTRACT

The present study attempts a preliminary analysis of the components of the water balance of the Johnstone Lake basin in South Saskatchewan. Its major contributions are the estimation of water deficit, surplus and runoff patterns according to the Thornthwaite climatic water balance method. Each component of the climatic water balance of the basin is studied for the 1921-1968 period and the runoff values are compared with measured data in an attempt to test the Thornthwaite method and its applications to present and future land use demands in the basin.

Water deficit in the basin has a great variation from year to year. The annual deficit averages about 9 inches, ranging from 7.6 inches to 9.9 inches. The mean annual water surplus in the basin is about 0.66 inch. This small surplus occurs in the spring from snow melt. Water surplus occurs usually in the spring, but moisture levels do not reach 4 inches capacity after April in over half of the years.

The relationship between measured and calculated annual average runoff is quite close, but the highest correlation coefficient for the two variables is only 0.61. The correlation level suggests that the Thornthwaite water balance method may be used more successfully for long term than for short term data. It is felt that the rate of snowmelt runoff during the months with mean temperature less than 30.2°F. can be considered to be zero. Snowmelt runoff should, in fact, better correspond with degree-days above freezing point based upon the daily maximum temperature. This method shows that most basins drain the surplus water at a rate closer to 75 per cent per month than the 50 per cent which Thornthwaite suggests.

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CHAPTER I

GEOGRAPHICAL FEATURES OF THE JOHNSTONE LAKE BASIN

Location and Physiography

The Johnstone (Old Wives) Lake drainage basin of southwestern Saskatchewan occupies an area of about 6,460 square miles in the short-grass and mixed prairie zone of Canada's agricultural heartland. It lies between longitude 105°35' and 108°32'W., and latitude 49°10' and 50°32'N. (Figure 1). The basin is backed on the north by the Wood Mountains, a rugged range which rises from the lake itself to ridge altitudes of over 3,000 feet. Land-use is given over almost entirely to grain growing and rangeland grazing. This farm-ranching economy requires a permanent water supply for effective usage of the grazing resources, and for reliable production of crops. This thesis seeks to assess the levels of permanency of this basin's water supply.

The basin forms part of the physiographic unit known as the Interior Continental Plain or Great Plains region. In Canada this unit comprises the prairie and forest areas of Manitoba, Saskatchewan, and Alberta, and lies between the Laurentain Shield on the east and north, and the mountainous Cordilleran region on the west. Bounded on the west by mountains and foothills of the Rockies, the "Prairie Provinces" consist of vast plains, gently sloping towards the east and northeast.

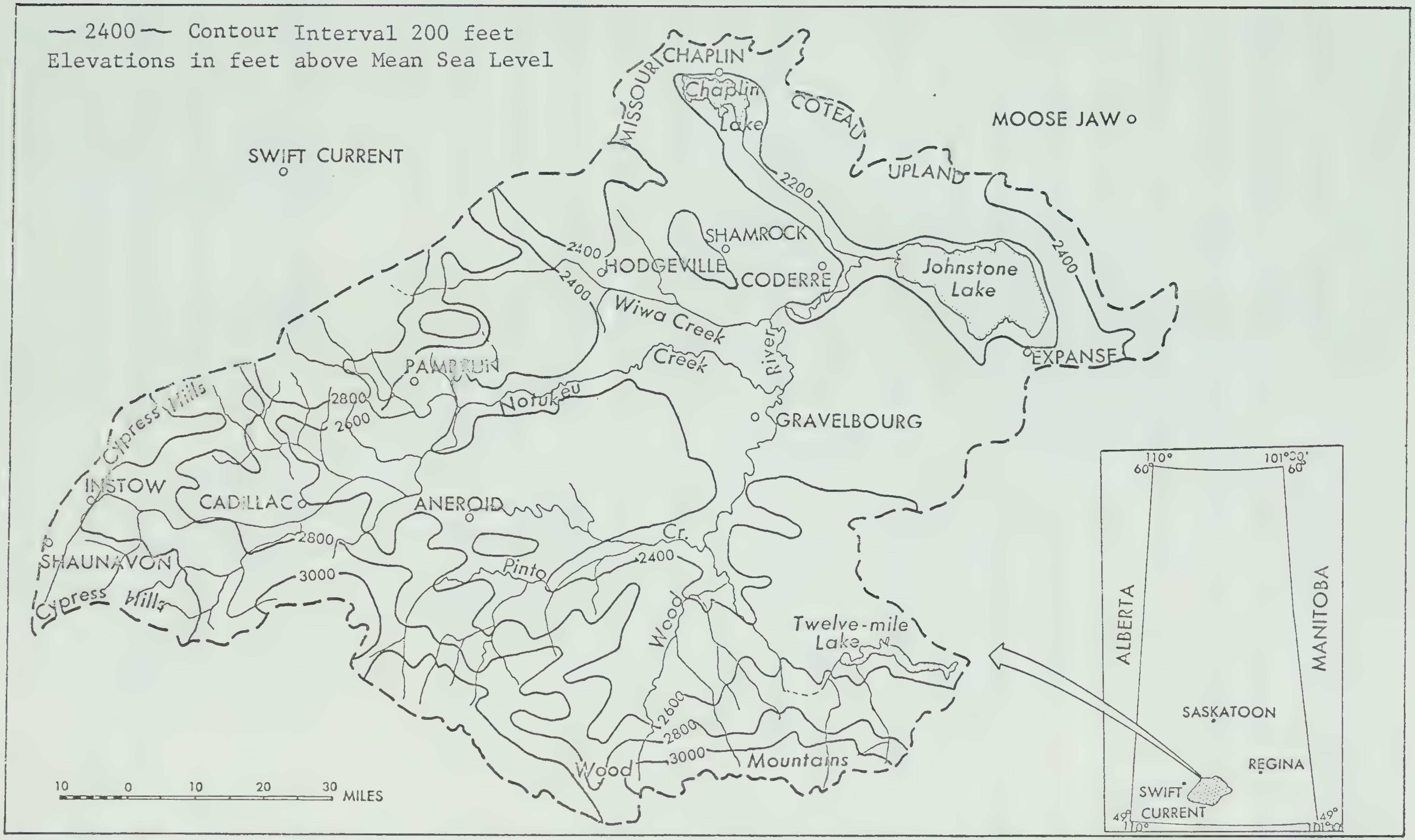

FIGURE 1. LOCATION AND TOPOGRAPHY OF JOHNSTONE LAKE BASIN

The lower part of the Johnstone Lake basin comprises the glacial drainage channels of Chaplin and the glacial lake beds of Johnstone, surrounded by the Missouri Coteau. East of the Coteau the topography is principally undulating to gently rolling. The elevations range from about 2,200 to 2,500 feet above sea level. West of the Missouri Coteau, the general elevations of the land are lower than to the east. The Cypress Hills and Wood Mountains in the southwest and south sections of the drainage basin, average over 3,000 feet in height. The Cypress and Wood Mountain uplands represent remnants of old plateaus which, through erosion, are now dissected by numerous deep valleys and coulees.

The basin is an internal drainage system subject to intermittent drainage during the spring months from both the Wood Mountains and the Cypress Hills. The direction of the drainage is northeast into Johnstone Lake via the Wood River and its tributaries. The most important tributary is Notukeu Creek, entering the Wood River from the west near Gravelbourg. Two other significant tributaries are Wiwa Creek and Pinto Creek. The Johnstone Lake reservoir is a shallow body of water about 110 square miles in area and, being without an outlet,is salty or alkaline.

Geology and Surface Deposits

The bedrock surface of the basin slopes to the northeast. The bedrock materials are of Upper Cretaceous and Tertiary age (Edmunds, 1944). The Bearpaw Formation which is Upper Cretaceous marine shales is the most widespread bedrock formation in the basin. To the south of the

GEOLOGICAL MAP, JOHNSTONE LAKE BASIN

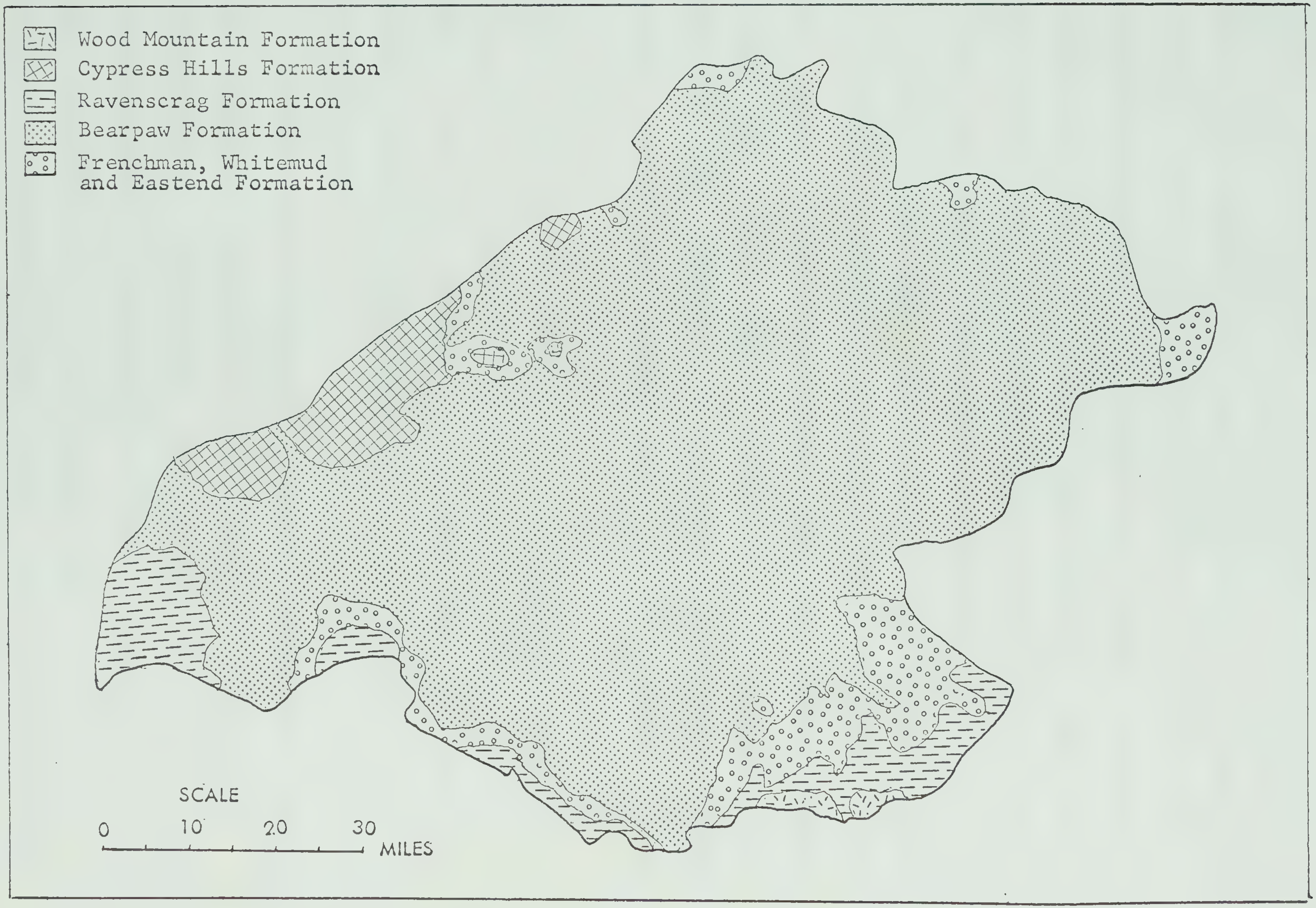

FIGURE 2

Johnstone Lake basin, the Eastend, Whitemud and Frenchman Formations occur. The most widespread Tertiary deposit is the Ravenscrag Formation in the south. It consists of a wide variety of sands, silts and clays and includes several lignite horizons. The Cypress Hills Formation which consists of Conglomerate and sandstone with minor interbedded clay and silt is found in the Cypress Hills area. The unconsolidated sand and gravel of the Wood Mountain Formation are limited to small thin deposits on the Wood Mountain Upland.

In Pleistocene times, the area, like most of the rest of Canada, was covered by a succession of ice sheet advances and retreats. The great thickness of ice at the central region of accumulation to north and west gave rise to pressure at the base and moved outward into the surrounding areas. Boulders of Pre-Cambrian rocks and younger limestone were carried south and mixed with shales and other sediments which were the surface rocks of the prairie region. The present topographic features are sometimes expressive of the type of moraine deposited. In general, this terminal or recessional moraine country is strongly rolling, with numerous potholes, and is often stony. The potholes may have resulted from the delayed melting of buried masses of ice (Edmunds, 1944).

The surface deposits are mostly glacial moraine, boulder clay and re-sorted till deposits. In many areas the mantle of glacial material is thin or nonexistent, resulting in exposure of the preglacial bedrock. In the Wood Mountains and Cypress Hills area, surface deposits are the mixed sedimentary types of Tertiary age. There are belts of complex soils formed on recently eroded hillsides or on recent deposits of the valley bottoms.

Climate

The basin lies in the south portion of the Mid-latitude Grassland climatic region. The western mountains form a fairly effective barrier to the maritime climatic influences from the Pacific and at the same time leave the area exposed to the inflow of cold Arctic air masses from the north. They are therefore more effective as a climatic control to the region than is the prevailing topography of the prairies themselves.

Summers are normally warm for the latitude and winters are usually long and cold. Winter temperatures on the Prairies may vary widely from month to month depending upon the character and path of air masses passing over the region. Winter temperatures in the lee of the Rockies reflect the warming effect of the chinook which occurs in the foothills from the Northwest Territories to the United States, but one which is most pronounced in southern Alberta with effects noticeable as far as Regina.

The Prairie Provinces lack sources of abundant precipitation. The precipitation minimum occurs in southwestern Saskatchewan and southeastern Alberta, with annual totals of less than 12 inches. The effectiveness of this already small amount is reduced by the strong summer sunshine and dry winds. In marked contrast to the Canadian Pacific coast with its winter maximum and perennial precipitation, the Prairies have a "wet" season from late May to early September and a relatively dry season during the late autumn, the winter and early spring.

Precipitation in the whole region shows wide variations from year to year. Its occurrence is principally caused by the action of summer cool waves from the Arctic regions. Moving southward, these waves lift warm, moist air which has accumulated on the Prairies. The

cooling due to the lifting, may provide general rains or local thunderstorms. General rains come from the lifting of extensive moist air masses moving northward from the Mississippi Valley and neighboring regions. Local showers, the more common pattern, arise from local ascent into dry, cold upper air masses. Failure of frequent excursions of cool northern air into the southern Prairie region during the summer produces droughts. Drought is most apt to occur in southeastern Alberta and southwestern Saskatchewan. The Johnstone Lake basin is part of this climatic region.

1. Precipitation

The Johnstone Lake basin itself is a part of the "Palliser triangle"[1]. The mean annual precipitation ranges from about 13 to 16 inches, being highest in the Cypress Hills (Figure 3). June to August shows a strong maximum. The 6 months, April to September, get 71 per cent of year's total. June has the most rain, and October or February is generally the driest month. The number of days per year with precipitation in the basin is less than 75. The precipitation is, moreover, not dependable from year to year. Both Currie (1953) and Longley (1953) have given statistical proof of the high variability of precipitation

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1. The Palliser triangle is a large dry area in southern Alberta, Saskatchewan and Manitoba, extending northward from the United States border approximately to latitude 52°N. and westward from longitude 100°W. to 114°W. It has been a regional geographic reference since Captain John Palliser explored the vast unsettled interior of southern Canada nearly a century ago.

MEAN ANNUAL PRECIPITATION (IN INCHES), JOHNSTONE LAKE BASIN, 1921-1968

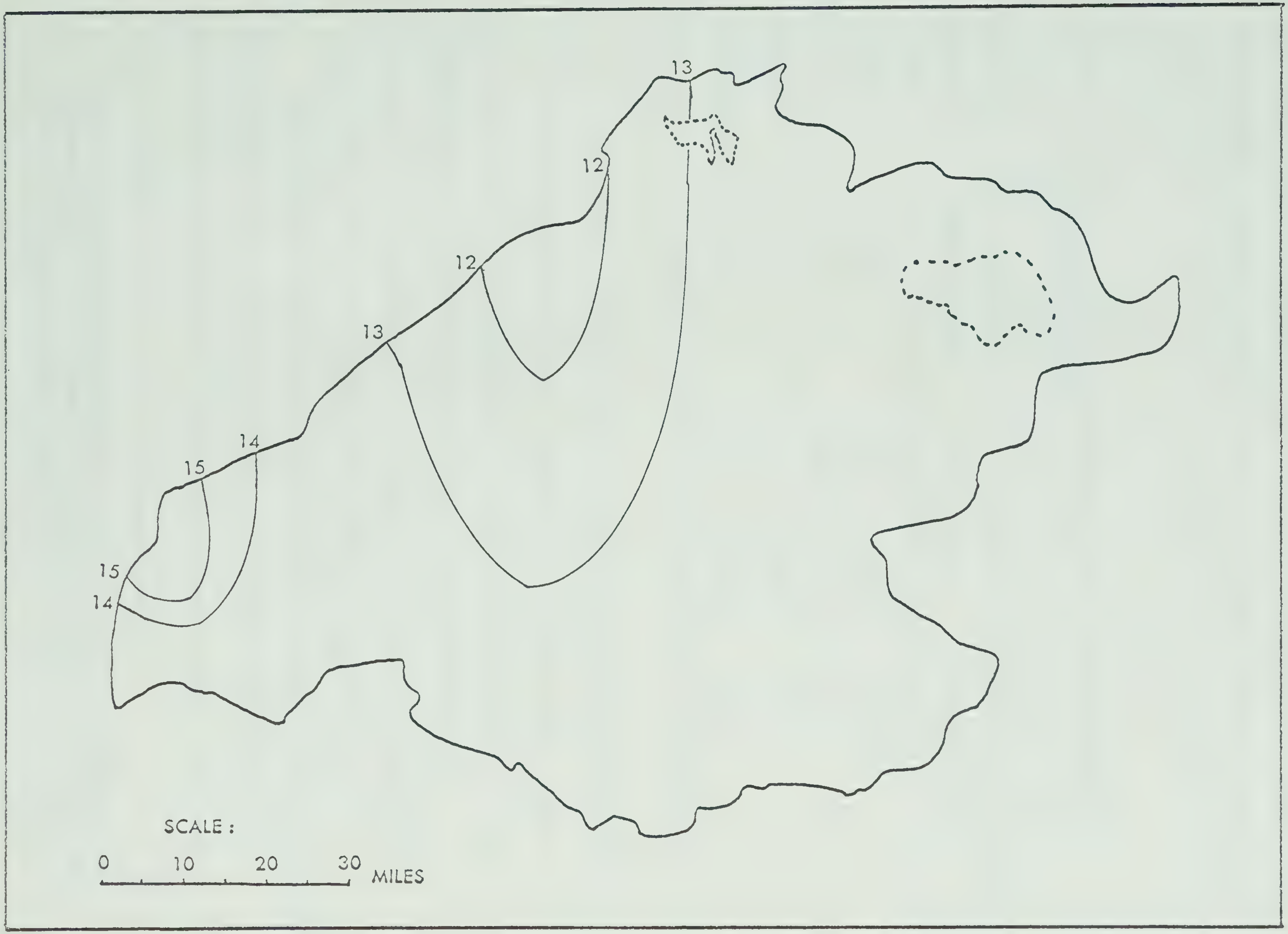


FIGURE 3

from year to year. The coefficient of variation[2] of annual precipitation is above 25 per cent (Table 1). This means approximately that in two out of three years the annual rainfall lies between 3/4 mean and 5/4 mean.

TABLE 1: THE COEFFICIENT OF VARIATION OF ANNUAL PRECIPITATION FOR SELECTED STATIONS.

Station	Number of Year	S D	Mean	Variation (%)
Aneroid	46	3.49	12.96	25.6
Cadillac	19	3.61	13.62	26.5
Chaplin	46	3.21	13.58	24.4
Gravelbourg	41	3.22	13.24	24.3

Variability of the monthly precipitation is greater than that for the annual and seasonal cases. Anywhere in the basin months may occur without a trace of precipitation. Data for the basin do not show any definite cycle of wet and dry years, nor do they indicate that precipitation is becoming less (see Table 17,18,19 and Appendix II). It is evident that years of low precipitation occur frequently.

As might be expected small daily totals are more frequent than large daily totals. For the months, April to September, Table 2 gives the percentage probability that a day with any precipitation, will have

2. Coefficient of variation equals the standard deviation divided by the mean, see R. W. Longley, "Variability of annual precipitation in Canada", Monthly Weather Review, Vol.81, No.5, 1953, p.131.

totals within the ranges (in inches) indicated. The probability of the totals being 0.25 inch or less exceeds 77 per cent in most of the basin. The probability of more than 1.00 inch is only 3 per cent. The winter snowfall follows a similar pattern. Light falls are many, heavy falls are few.

TABLE 2: PROBABILITY OF DAILY PRECIPITATION DURING APRIL TO SEPTEMBER, FOR THE SELECTED STATIONS IN THE JOHNSTONE LAKE BASIN.

Station	Probability of Daily Precipitation			
	<0.25	0.26-0.50	0.51-1.00	>1.00 (inch)
Aneroid	84	9	5	2
Chaplin	78	11	7	4
Gravelbourg	83	8	6	3
Instow	77	12	8	3

Drought does far more harm to agriculture than excess precipitation in the basin. It has been responsible for almost total failure of crops, for accelerated soil erosion through increasing the vulnerability to wind action, and for shortages of fodder and water for livestock[3]. The longest period of drought[4] for the wet season of major dry years is a clear indication of the degree of seriousness of the drought problem in the basin (Figure 4).

3. For instance, serious droughts occurred in 1936, 1937 and 1949.

4. Conrad considers 0.25 inch of precipitation the minimum necessary to break a drought. See V. Conrad and L. W. Pollak, Methods in Climatology, 2nd. ed. Harvard University Press, 1950, p.213.

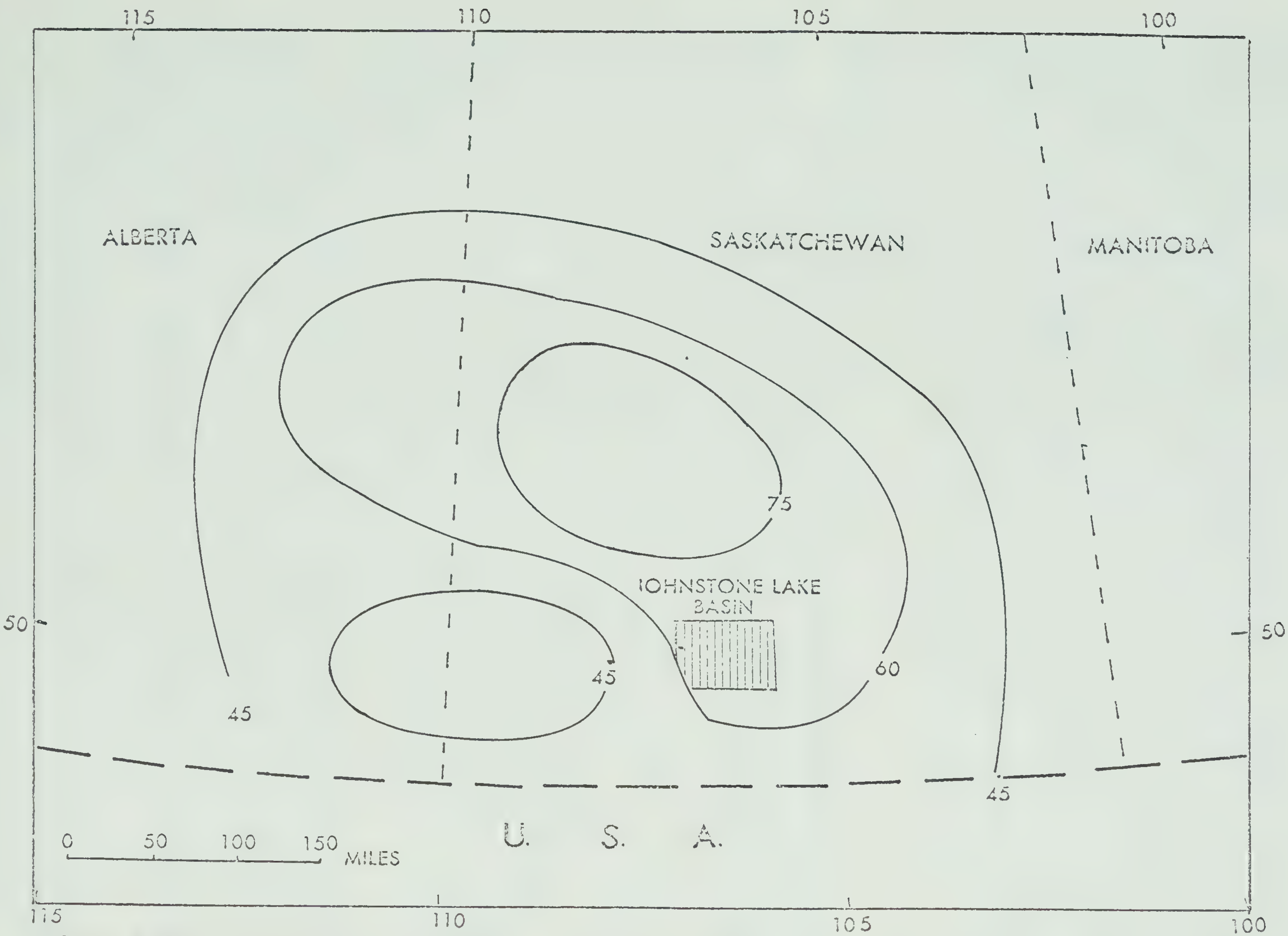


FIGURE 4. PERIOD OF DROUGHT—THE LONGEST PERIOD WITH LESS THAN 0.25 OF PRECIPITATION-DURING THE WET SEASON (APR.1-SEPT.1) OF MAJOR DRY YEARS (1936, 1945, 1949). (AFTER VILMOW)

Like the total precipitation, the amount occurring as snowfall for this basin is one of the lowest in the province of Saskatchewan, ranging from 25 to 40 inches. In spite of the low amounts, the land remains snow covered from early November till mid-April – as long as in the more northerly plains. Median depth of snow cover is below 8 inches on February 28 (Potter, 1965). The major portion of snowmelt occurs during late March or early April under the strong pre-summer insolation. Due to the flat terrain and lack of forest cover, melting occurs practically simultaneously over the entire drainage basin.

2. Temperature

The mean annual temperature of the Johnstone Lake basin varies from 37° to 39°F. A very large temperature range, averaging about 60°F., is an outstanding feature. The annual variability (standard deviation) of temperature in the area is about 2°F.

Mean monthly temperature is below 32°F. in each of the 5 months, November to March. The coldest month is January. The highest temperature is in the southwest. Towards the northeast and east the mean decreases rapidly. The mean daily maximum is below 32°F. in the 3 months, December to February. An absolute low temperature has been recorded at -50°F. over most of the basin.

Mean monthly temperature exceeds 50°F. in each of the 5 months, May to September. The warmest month is July, most areas having above 67°F. The daily maximum temperature may occasionally rise to over 105°F. An absolute maximum temperature of 110°F. has been recorded at Chaplin.

The transition from the cold of winter to the warmth of summer is effected with remarkable rapidity. There is virtually one month of spring: April, and one month of autumn: October, in each of which the

mean temperature is about 40°F. The October mean temperature is somewhat higher.

The mean temperature of each month varies greatly from the yearly mean, especially the winter months. Similarly, the mean daily maximum and the mean daily minimum temperatures in any month are liable to large deviations from year to year. As an example of extreme departures in winter, in January 58°F. in 1931 and - 53°F. in 1954 were recorded for Aneroid in the Johnstone Lake basin.

3. Wind and Sunshine

The Prairies receive a high average of sunshine for the latitude; the annual totals range from 2,000 to 2,500 hours. July is usually the sunniest month with totals exceeding 300 hours at most stations. December is the dullest month of the year with all stations showing totals of less than 100 hours.

Data for bright sunshine and wind within the basin itself are not, however, readily available. They are probably similar to those recorded at Swift Current and Moose Jaw, which are located respectively 8 miles to northwest, and 10 miles to the northeast from the northern boundary of the basin. The prevailing winds in the area in winter are predominantly southwest winds. Southwest winds are less frequent in the warmer times of the year, but they are then associated with conditions warmer and drier than those from other directions. They often aggravate damage to crops when soil moisture is already deficient.

Average monthly wind speeds throughout the basin in general seldom exceed 16 miles per hour. The speeds are highest in spring and

winter, lowest in late summer (Table 3). Topography affects wind directions and speeds in the basin. In the river valleys, there is a great tendency for winds to parallel the axis of the valley. Departures from the normal monthly speeds are generally larger for monthly speeds above the average than for those below the average in the basin. Above average speeds are more frequent during March, April and August. The fall in speeds during July helps to decrease moisture loss from evapo-transpiration, a time when the moisture requirements of cultivated crops are greatest.

TABLE 3: AVERAGE WIND SPEED IN MILES PER HOUR AT MOOSE JAW (1) AND SWIFT CURRENT (2), 1955-1966.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
1.	14.9	14.5	14.8	15.0	15.5	14.1	12.0	12.3	14.7	14.7	15.0	15.2	14.4
2.	16.3	15.6	15.1	15.1	15.2	14.1	12.6	12.7	14.9	15.3	15.8	16.4	14.9

Source: Canada-Department of Transport-Meteorological Branch, Climatic Normals Vol.5: Wind, Toronto, 1968, p.35-36.

The duration of sunshine is virtually a measure of the amount of unobscured solar radiation received at a site. The average number of hours of bright sunshine in the basin varies regularly throughout the year, rising to a maximum in July and dropping to a minimum in December. The mean annual total exceeds 2,250 hours (Table 4). The actual duration increases rapidly, of course, with increasing length of day from winter to summer. The percentages of the possible number of hours

of bright sunshine rise to a value ranging from 60 to 80 per cent in summer, and drop to values from 30 to 40 per cent in winter. A July or August with one or more completely overcast days is extremely rare. Only in the years with greater precipitation variabilities is the maximum number of overcast days in the sunniest month likely to exceed 10 per cent.

TABLE 4: NUMBER OF HOURS WITH BRIGHT SUNSHINE AT MOOSE JAW (1) AND SWIFT CURRENT (2), 1931-1960.

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
1.	93	115	153	210	258	264	341	288	209	172	96	84	2283
2.	84	120	147	209	263	263	345	291	198	169	106	86	2281

Source: Canada-Department of Transport-Meteorological Branch, Climatic Normals Vol.3: Sunshine, Cloud, Pressure, and Thunderstorms, Toronto, 1968, p.1.

The ultimate source of practically all the energy for all physical and biological processes occurring on earth is solar radiation. It is now becoming increasingly clear that solar radiation requires further study as a component of the plant environment. This is particularly clear in relation to growth of plants or in the study of soil moisture levels and of evaporation.

In the basin the estimated annual radiation income is over 129,700 cal/sq.cm. (Titus and Truhlar, 1969). The highest monthly income is about 18,600 cal/sq.cm. in July and the lowest is in December, about 3,100 cal/sq.cm. The measured radiation at the Swift Current

South Farm is shown in Table 5.

TABLE 5: RADIATION AT SWIFT CURRENT SOUTH FARM IN cal/sq.cm., 1961-68.

January	3,879	July	18,894
February	5,878	August	15,016
March	10,846	September	10,249
April	13,054	October	7,215
May	15,845	November	3,821
June	15,878	December	2,933
		Year	123,508

Source: Canada-Department of Transport-Meteorological Branch, Monthly Records, 1961-1968.

The climate of the basin may then be classed as a semi-arid temperate continental type. It has a hot, sunny, and long summer compared with other areas of Saskatchewan, and a cold winter similar to other prairie areas. There is a low seasonal and annual precipitation and a high evapotranspiration potential. Drought potential will consequently be a serious handicap to the development of agriculture in the basin.

Vegetation

The vegetation of the basin consists of two types of grassland, designated short- grass prairie in the southwest, and mixed prairie in the northeast. In the short-grass prairie, the native cover, consists chiefly of *Bouteloua gracilis* (Blue grama grass) associated with other

dominants including Poa secunda (Sandberg's blue grass) and Carex filifolia (Niggerwool) in the short-grass form (Clark et al, 1947). The midgrass dominants which comprise Stipa comata (Common spear grass), Agropyron smithii (Blue-joint or western wheat grass) and Koeleria cristata (June grass) tend to be dwarfed in stature in this association. Involute-leaved sedge is also of widespread occurrence. Trees are absent from the short-grass prairie except in certain moist, sheltered locations or on soils possessing a high water table, e.g. Populus tremuloides (Aspen) and Salix spp. (Willow) (Ellis et al, 1965).

In typical mixed prairie, the short-grass species are abundant. Plants including Sumphoric carpus occidentalis (Western snowberry), Salix spp. (Willow) and Populus tremuloides (Aspen) are found in the mixed prairie.

Highly saline or " alkali " areas are characterized by a vegetation cover of salt tolerant grasses, e.g. Distichlis stricta (Alkali grass) and Puccinellia nuttalliana (Nuttall's salt-meadow grass). The wet slough and wet meadow areas are occupied by sedges, rushes and various moisture-loving grasses, e.g. Carex atherodes (Awned sedge), Eleocharis palustris (Spike rush),and Beckmannia syzigachne (Slough grass).

Agricultural land is the most valuable natural resource of the Johnstone Lake basin. The land under crops is about 38.7 per cent of the total area, and summer fallow occupies about 28.5 per cent (Table 6). These percentages are quite stable from year to year. Wheat is the most important crop in the basin. Irrigated farmland under major irrigation projects is approximately 11,450 acres, largely backflood irrigation. The possibility of extending the irrigation land

in the area, is a topic of discussion later in the thesis.

TABLE 6: THE LAND-USE TYPES IN THE JOHNSTONE LAKE BASIN, 1966.

	Under crops	Summer fallow	Pasture	Woodland	Other*
Area (acres)	1,450,900	1,073,300	136,200	3,100	1,091,900
Percentage	38.7	28.5	3.6	0.1	29.1

* This term includes the area of barnyards, home gardens, lanes, road, natural pasture, brush pasture, grazing or waste land, slough, marsh, and rocky land, etc.

Source: Canada-Dominion Bureau of Statistics, 1966 Census of Canada: Agriculture- Saskatchewan, Vol.5, No.2, 1968.

Soil

Because of dry weather, short-grass and mixed prairie, geological deposits, and other factors in the area, the most widespread soil is medium-textured Brown soil, ranging in surface color from light brown to greyish brown. The color changes to a faint reddish brown when the soil is moist. The A_1 horizons are relatively thin in most soils, and the average organic matter content is lower than than that of the other grassland soils, e.g. Dark Brown soil and Black soil (Mitchell et al, 1944).

The range in soil texture is from heavy clay to sand loam. Most of the basin is clay loam or loam. Glacial stones present in soils in most areas have now been cleared from cultivated land. Lack of efficiency in handling soil moisture is the principal handicap to their agricultural use.

In the pothole topography, the soil profile is poorly drained and frequently contains undesirable quantities of soluble (alkali) salts. The most important soluble salts are sodium sulphate (Glauber's salts), magnesium sulphate (Epsom salts) and calcium sulphate (Gypsum) (Moss, 1965). Salts may be observed if the soil is allowed to dry – a white efflorescence or light crust will appear on the surface of the soil as it dries. They occur in the beds of streams, dry lakes, and sloughs. The saline soils are developed chiefly on recent alluvial and lacustrine deposits, and are found in the Chaplin Lake, Kincaid, and Boswells areas of the basin.

Summary

The Johnstone Lake basin has a semi-arid temperate continental climate. Annual and seasonal precipitation is low and variable. Since drought will likely be a serious handicap to the development of agriculture, it is important to assess the demand for water and the amount available in the basin. This basin is a closed lake region and has a relatively uniform distribution of vegetation and soil. Consequently, conditions are suitable for use of the water balance technique to estimate water demand and supply.

CHAPTER II

WATER BALANCE CHARACTERISTICS OF THE JOHNSTONE LAKE BASIN

All precipitation falling on a watershed is transformed into surface runoff, evapotranspiration, infiltration into the soil, or storage on the surface of the land. These are not mutually exclusive. For a given time interval and land area, it is possible to draw up the water balance of such items, as a measure of the amount of water flowing into and out of a given portion of the basin.

The "water balance method" is a measurement of continuity of flow of water. The term has gained popularity over the past 20 years among climatologists, geographers, hydrologists, geologists and others concerned with water problems. It has been widely used as an analytical tool. It has been applied to a small drainage basin (Carter, 1955, 1956, 1958; Sanderson, 1966) and to the earth as a whole (van Hylckama, 1956). In this thesis the term water balance refers to the climatic water balance between precipitation and evapotranspiration, as developed and applied by C. W. Thornthwaite (1944, 1948) and others.

The empirical expression of the water balance used in this thesis is

$$Ppt = (PE - D) + S \pm SC \quad \text{--------------------} (1)$$

where Ppt = Precipitation

PE = Potential Evapotranspiration

D = Deficit

S = Surplus

SC = Storage Change

Potential and Actual Evapotranspiration

The combined evaporation from the soil and transpiration and evaporation from plants is called evapotranspiration. It represents an important mass transfer of water and energy from the earth back to the atmosphere, the reverse of precipitation within the hydrologic cycle. The usefulness of evapotranspiration data is recognized by people in many fields of endeavor.

Conceptually potential evapotranspiration (PE) is the amount of water which will be evaporated and transpired from a surface completely covered with vegetation where water is a non-limiting factor in the soil for the use of vegetation (Thornthwaite and Mather, 1955). The term "consumptive use", familiar in irrigation literature, is equivalent to PE. Data on PE are useful for estimating irrigation requirements, moisture conservation, safe yield of ground water basins (Freeze, 1969b) water yield from mountain watersheds, and streamflow depletion in river basins. Calculation of PE is also used in showing the comparative amounts of heat available for growth in different regions, in scheduling crops in order to provide for balanced harvest operations and in relation to farm size and crop patterns (McDonald, 1968). It has also been used in estimating soil trafficability.

The measurement of PE still presents many difficulties. Potential evapotranspirmeters and various evaporation pans are commonly used to measure PE. These instruments are expensive, large, and difficult to install and use. Direct determination of PE is laborious and time-consuming, therefore numerous methods have been developed to estimate water requirements for areas in which evapotranspiration measurements are not available. Recognition of its importance as a climatic factor

and element highlights the lack of basic data, and the difficulties in measurement met with in the field methods have accounted for the great efforts made to develop evapotranspiration equations that can relate the evapotranspiration with readily available climatic data (Lowry and Johnson, 1942; Thornthwaite, 1948; Penman, 1948; Blaney and Criddle, 1950).

The best known example of an empirical relationship based on meteorological and geographic factors is the formula developed by Thornthwaite in 1948. His equation is based on an exponential relationship between mean monthly temperature and mean monthly evapotranspiration. The formula, however, gives only an unadjusted rate of PE. It is necessary to adjust the unadjusted rates by a factor which varies with the month and the latitude of the station (Thornthwaite and Mather, 1957). The Thornthwaite formula is based largely on experience from lysimeter and watershed observations of water loss in the central and eastern United States. It is simple, easy to use with nomograms and tables, and makes use of the most readily available climatic data, temperature and precipitation. Considering its simplicity and the obvious limitations of the available data, this equation does surprisingly well (Penman, 1956).

The formula works well in the temperate continental climates of North America, for which it was devised, and where temperature and radiation are strongly correlated (Sanderson, 1950a, 1950b, 1954; Mather, 1954; King and de-Heer-Amissah, 1965; Hobbs and Krogman, 1966; Laycock, 1967). The Thornthwaite formula will be used to compute PE for the Johnstone Lake basin station where available meteorological data are temperature and precipitation only.

TABLE 7

THE CLIMATIC STATIONS IN THE JOHNSTONE LAKE BASIN

Station	Lat. N. ° '	Long. W. ° '	Elevation (feet)	Period of Records (1921-1968)
Aneroid	49 42	107 18	2443	1923-68
Bishopric	50 00	105 47	2230	1948-51,65-68
Cadillac	49 44	107 45	2567	1923-27,41-59
Cardross*	49 49	105 39	2300	1955-63
Chaplin	50 28	106 39	2202	1921-66
Eastleigh	50 17	106 12	2200	1949-68
Gravelbourg	49 52	106 33	2297	1928-68
Hodgeville	50 07	106 58	2285	1956-68
Instow	49 43	108 17	2964	1954-68
Moose Jaw*	50 20	105 33	1857	1921-68
Pambrun	50 00	107 26	2550	1957-68
Readlyn*	49 35	105 39	2219	1955-68
Shamrock	50 10	106 41	2383	1957-68
Shaunavon	49 39	108 24	3010	1921-68
Swift Current*	50 17	107 41	2677	1921-68

* These stations are out of the Johnstone Lake basin.

Source: Canada-Department of Transport-Meteorological Branch, Monthly Records, Toronto, 1968.

The climatological stations used in this study with their locations, altitudes, and the period of data coverage appear in Table 7. For the basin as a whole, with the exception of the Wood Mountain area, station coverage is good. Monthly data of average temperature and precipitation were obtained from the Canadian Monthly Records for 1921 to 1968. The procedure for computing the climatic water balance was followed for each of the 15 stations shown in the table.

Annual PE values in the Prairie Provinces show a decrease from south to north with some variations due to elevation in the western regions, and to the proximity of Hudson Bay in the northeast. Values range from 16 inches to 24 inches (Laycock, 1967). The major patterns for the Johnstone Lake basin are shown in Figures 5,6 and 7. The mean annual PE is about 22 inches. It has been calculated from 11 weather stations with values ranging from 18.34 to 22.27 inches. The district with the lowest PE value is in the valley of the Cypress Hills at Instow where there is a lower mean summer temperature. In general, PE is concentrated between April to October. In the other months, there is theoretically no PE since the monthly temperatures are below 32°F. The highest monthly PE is in July, about 5.40 inches, and the absolute highest was 6.58 inches at Aneroid in 1936. Both annual and monthly PE patterns show much less variation than this (Table 8).

TABLE 8: POTENTIAL EVAPOTRANSPIRATION PATTERNS FOR THE SELECTED STATIONS

Station	Year	Mean (in.)	Maximum (in.)	Minimum (in.)	S D (in.)	Coe. of Var. (%)
Aneroid	1923-68	22.05	24.76	20.20	1.00	4.5
Chaplin	1921-66	22.01	23.78	20.33	0.82	3.7
Gravelbourg	1928-68	22.28	24.16	20.17	0.97	4.3

FIGURE 5. COMPARISON OF CLIMATIC WATER BALANCE FOR ANEROID (4 INCH MOISTURE HOLDING CAPACITY)

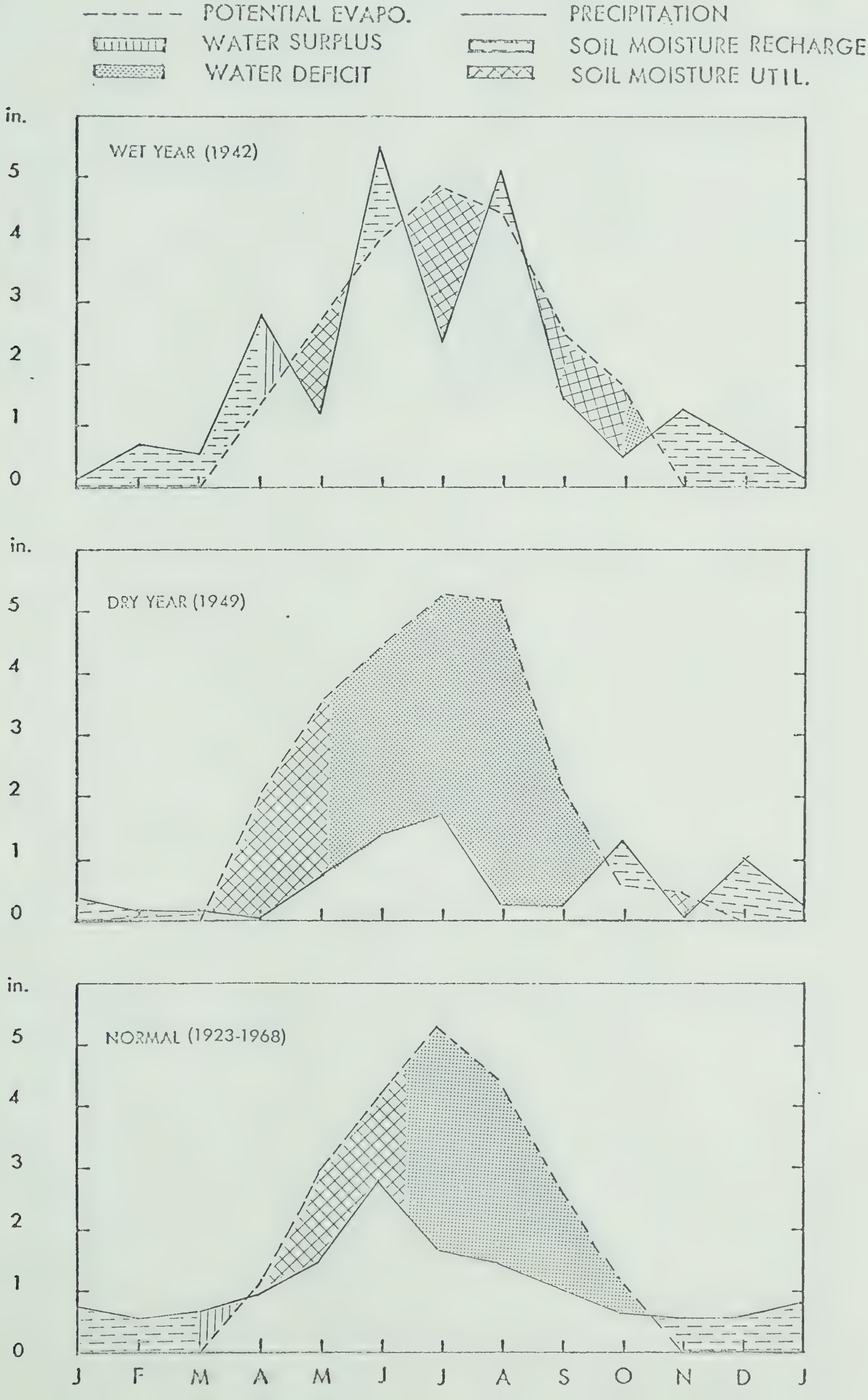


FIGURE 6 COMPARISON OF CLIMATIC WATER BALANCE FOR CHAPLIN
(4 INCH MOISTURE HOLDING CAPACITY)

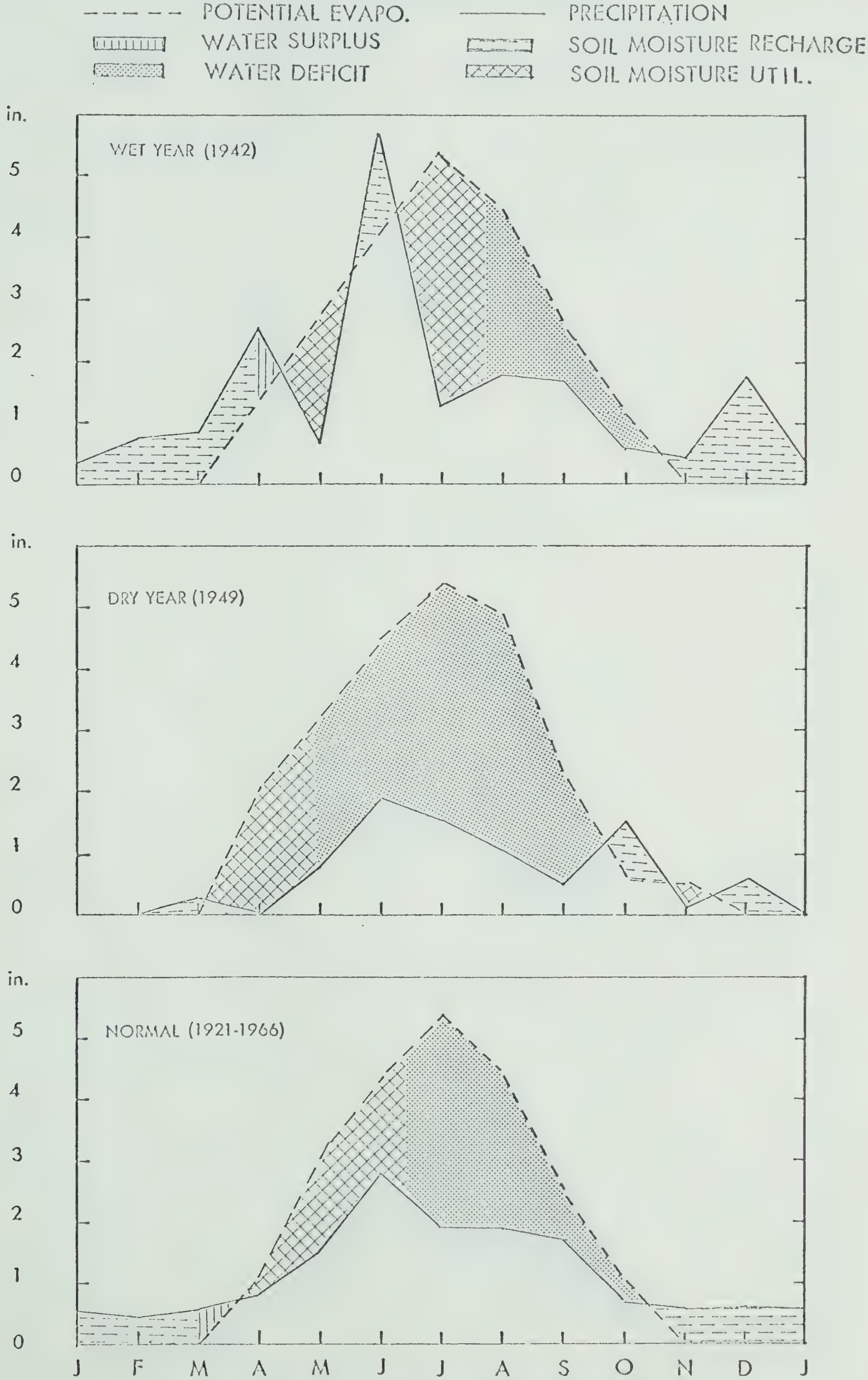
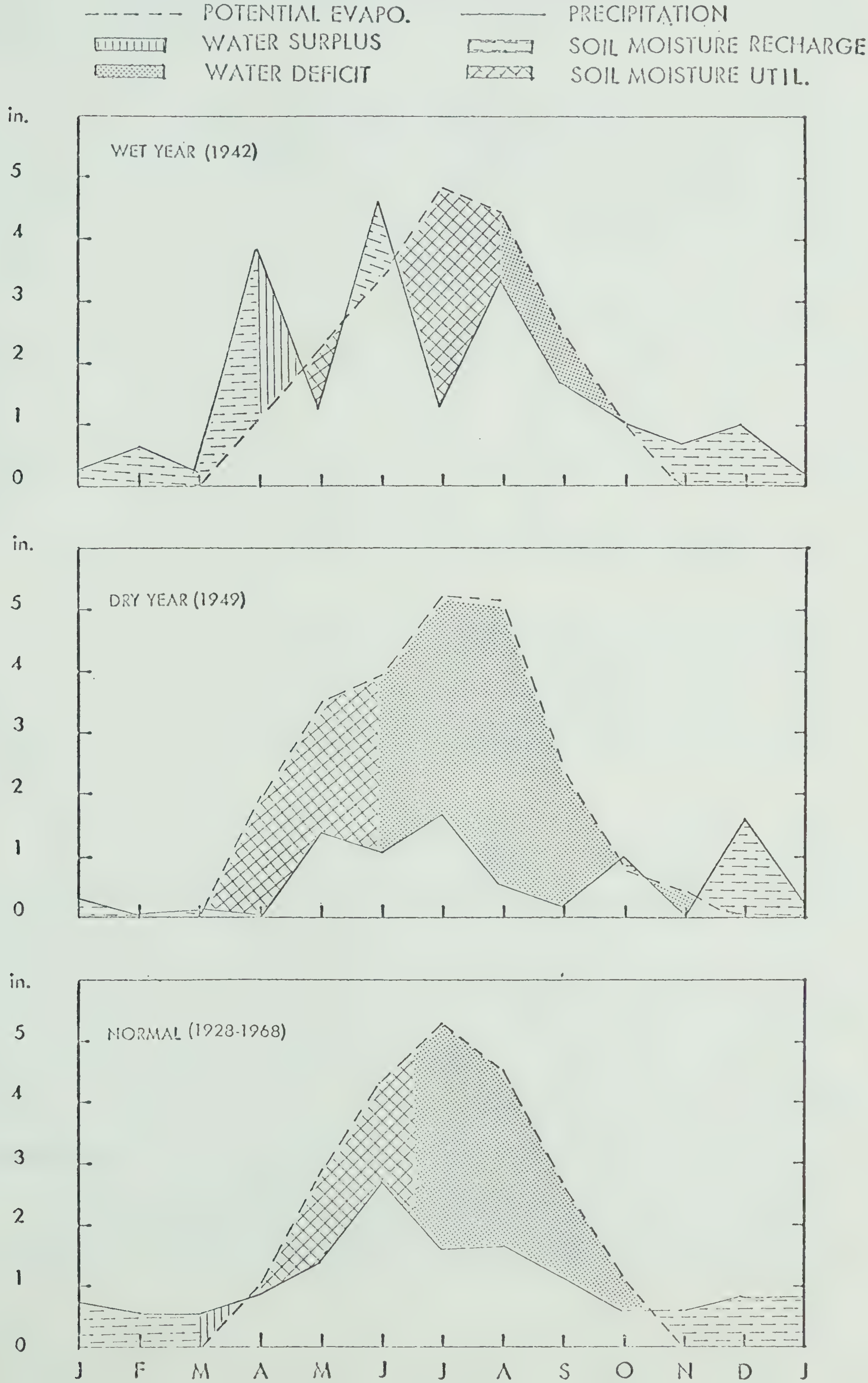


FIGURE 7 COMPARISON OF CLIMATIC WATER BALANCE FOR GRAVELBOURG (4 INCH MOISTURE HOLDING CAPACITY)



The standard deviation from normal in the summer months is very small, but greater differences exist at the beginning and the end of the season (Table 9).

TABLE 9: POTENTIAL EVAPOTRANSPIRATION PATTERNS AT GRAVELBOURG, 1928-68.

Class	April	May	June	July (in inches)	Aug.	Sept.	Oct.	Year
Mean	1.06	2.95	4.38	5.36	4.56	2.65	1.16	22.28
Maximum	2.42	3.99	5.30	6.17	5.25	3.50	1.93	24.16
Minimum	0.00	2.39	3.67	4.52	4.75	1.59	0.28	20.17
S D	0.57	0.22	0.10	0.07	0.08	0.44	0.43	0.97

PE is a climatic quantity which depends on the energy available for vaporising water. The actual evapotranspiration (AE) of a place depends upon PE, precipitation and the availability of soil moisture to growing vegetation.

The available soil moisture is a rather complex factor, dependent upon precipitation and the moisture holding capacity of the soil. The soil moisture holding capacity depends on two main factors: the soil type and the vegetation cover. The moisture holding capacity of soils ranges for the very coarse to fine-textured soils, from about 1 inch to 5 inches per foot of soil depth. Table 10 by Colman (1948) indicates the moisture holding capacities of soils of different textures.

The essential item for the water balance, however, is not the total depth of stored water but only the part which is within reach of

TABLE 10: SOIL MOISTURE STORAGE VALUES OF SOIL TEXTURE CLASSES.

Soil Texture	Moisture Content in Inches of Water Per Foot of Soil Depth				
	at Pore Saturation	Detention Storage	Moisture Holding Capacity	Retention Storage	at Wilting Point
Sand	5.0	4.1	0.9	0.5	0.4
Sandy loam	5.0	3.2	1.8	1.1	0.7
Loam	5.0	2.3	2.7	1.6	1.1
Clay loam	5.4	2.0	3.4	1.7	1.7
Clay	5.4	0.4	5.0	2.5	2.5

Source: Coleman(1948).

plant roots for transpiration and evaporation. How much of the total storage capacity will be used is largely determined by the depth to which plant roots penetrate the soil. One factor which complicates the relation between depth of rooting of a plant and the type of vegetation is that the same plants will send roots to different depths in different types of soil. Their roots may absorb water from the soil at any depth to which they penetrate; and there is a fairly well-defined upper limit to the force with which they can extract water from the soil.

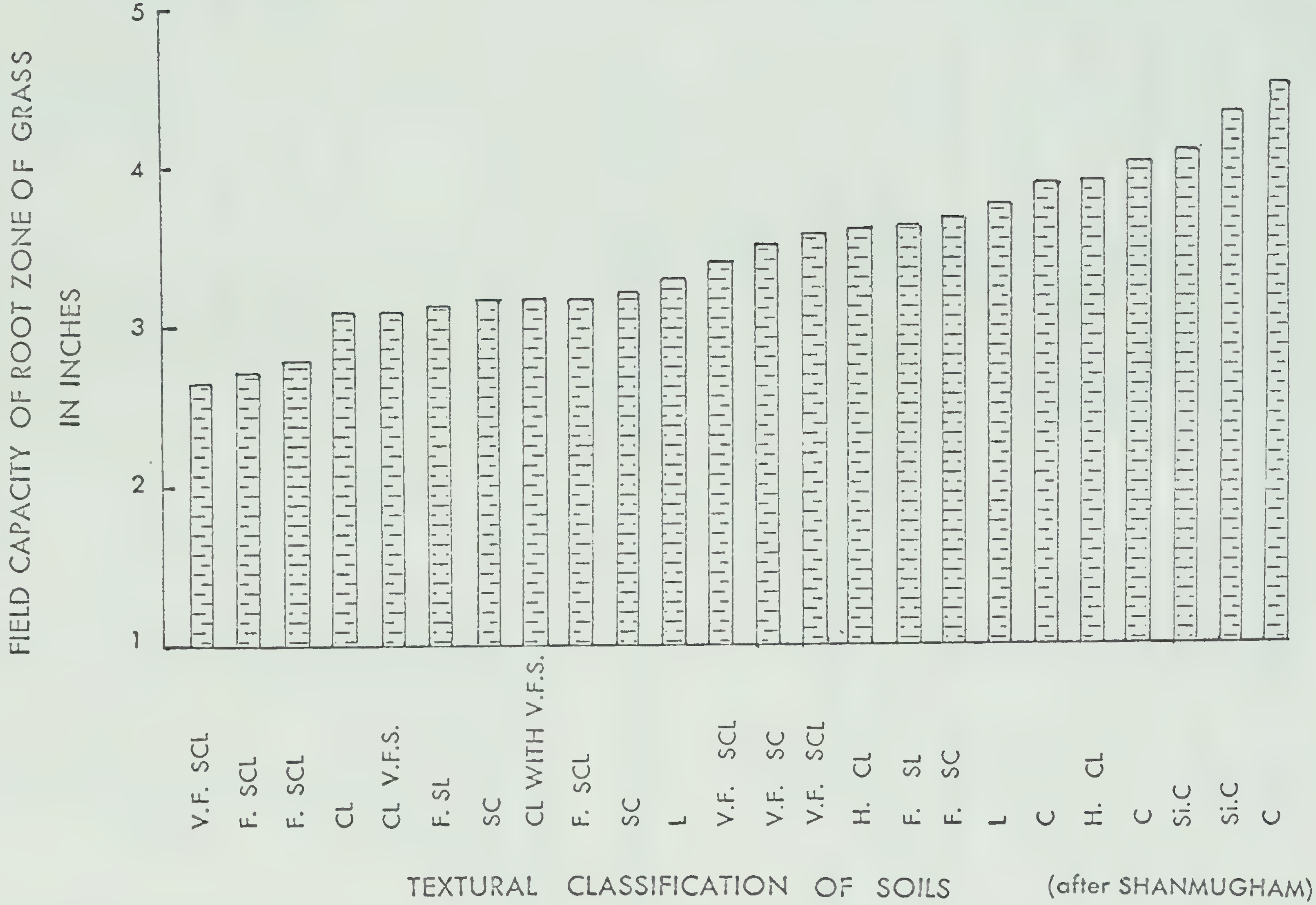
Precipitation water that reaches the soil but does not immediately enter it lies upon the soil surface. Water falls upon the soil surface and gathers in pools toward lower places where it enters the soil or moves into channels. The rate of water flow on the soil surface depends upon the gradient of slope, the roughness of the surface, and the degree to

which the flow is concentrated. The steeper the slope, the greater is the velocity and hence the smaller is the time of overland flow. Vegetation acts on the surface flow of water by providing roughness for the surface, cross-slope diversions, and interference to water movement. Surface roughness is produced by the growth of plants and by the decomposition and incorporation of plant remains into the soil. This kind of surface roughness is more marked in uncultivated than in cultivated lands because in the latter the natural roughening effect is largely destroyed by cultivation and is replaced with roughness produced by tillage equipment. The net effect of vegetation on runoff is to provide larger periods for infiltration, less opportunity for concentration in rills and decreased energy to cause erosion.

If the rainfall intensity is higher than the initial rate of infiltration, two things may occur separately or simultaneously on bare soil. The splashing of large raindrops may break up the soil aggregates and soil particles may seal up the pore spaces resulting in a larger amount of surface runoff than would otherwise be the case.

In the Johnstone Lake basin, the short-grass prairie, mixed prairie and grain crops are the plants in the vegetation cover. The water holding capacity of the soil has been estimated and determined in the field (Shanmugham, 1964) to be about 4 inches. This is the approximate average for the different types of soil and root depths in the basin (Figure 8). The depth of 4 inches of moisture holding capacity is used in this thesis in the computing procedure of the water balance. The depths of 2 inches and 6 inches of moisture holding capacity represent the different growing stages of crops at the seeding and maturation stages respectively. They will be used as supplemental

FIG. 8. BAR GRAPH OF FIELD CAPACITY VS. TEXTURAL CLASSIFICATION OF SOIL



LEGEND:

C — CLAY	S — SAND	SCL — SANDY CLAY LOAM	H — HEAVY
L — LOAM	SC — SANDY CLAY	Si.C — SILTY CLAY	V — VERY
CL — CLAY LOAM	SL — SANDY LOAM		F — FINE

values to explain the different situations encountered at different times and with various crops in the basin.

AE, like PE, is concentrated between April and October. In April, the values of AE equal those of PE. From May, PE usually exceeds precipitation and water needs are met by moisture stored in the soil and available to plants at root depth (see Figure 5-6). In time, the soil moisture is exhausted and a water deficit occurs. The AE is less than PE. The average highest monthly AE is in June. Annual AE patterns for various soil moisture holding capacities are listed in Table 11. Reference to Table 11 shows that as soil moisture holding capacity increases the AE increases.

TABLE 11: ACTUAL EVAPOTRANSPIRATION PATTERNS FOR THE SELECTED STATIONS.

Station	Period	Precipitation	PE	AE for Various Soil Moisture Holding Capacities		
				2-inch	4-inch	6-inch
		(in inches)				
Aneroid	1923-68	12.95	22.05	11.19	12.32	12.65
Chaplin	1921-66	13.39	22.01	11.73	13.12	13.30
Gravelbourg	1928-68	13.24	22.28	11.35	12.80	13.16

Soil Moisture Retention Patterns

Soil moisture retained from the beginning of the snowmelt period is an important factor in influencing runoff and water use patterns in areas of cultivated and natural vegetation during the summer months.

TABLE 12

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR ANEROID

4 inch Moisture Holding Capacity of Soil

Year	April	May	June (in inches)	July	Aug.	Sept.	Oct.
1923	1.77	0	4.00	2.01	0	0	0
1924	1.51	0.32	0.96	0	0	0	0.19
1925	4.00	2.33	0.49	0	0	0.55	2.33
1926	2.62	0.86	1.53	0	0	0	0
1927	3.11	4.00	2.31	0	0	0	0
1928	2.25	0	0.96	0	0	0	0
1929	2.15	0.56	0	0	0	0	0
1930	2.63	0.12	0	0	0	0.01	0.13
1931	0.11	0	0	0	0	0	0
1932	1.76	0	0	0	0	0	0.17
1933	1.59	1.12	0	0	0	0	0.35
1934	1.85	0	0.50	0	0	0.67	0
1935	2.34	1.53	1.11	0	0	0	0
1936	2.38	0.05	0	0	0	0	0
1937	1.47	0	0	0	0	0	0
1938	3.03	3.91	2.14	0	0	0	0
1939	1.65	2.13	4.00	0	0	0	0.34
1940	4.00	1.44	1.32	0	0	0	0
1941	2.16	0	0	0	0	0	0
1942	4.00	2.43	3.88	1.28	1.96	0.83	0
1943	2.44	2.26	1.34	0	0	0	0.74
1944	0.89	0	0	0	0	0	0
1945	3.92	2.23	0.74	0	0	0	0
1946	0.62	0	0	0	0	0	0.21
1947	3.99	2.85	1.40	0	0	0	0
1948	4.00	2.24	0	0	0	0	0
1949	0.27	0	0	0	0	0	0.78
1950	3.75	1.64	0	0	0	0	0
1951	3.65	0.27	0.86	0	0	0	0.16
1952	1.93	0	0	0	0	0	0
1953	4.00	4.00	2.91	0	0	0	0
1954	4.00	3.45	3.26	0	0	0	0
1955	2.63	2.55	0	0.36	0	0	0
1956	0.87	0	0	0	0	0	0
1957	2.06	0	0	0	0	0	0.20
1958	2.51	0	0	0	0	0	0
1959	1.64	0	0	0	0	0	0.35
1960	0.74	0	0	0	0	0	0
1961	3.25	2.02	0	0	0	0	0.22
1962	2.67	0.90	0	0	0	0	0
1963	0.89	0	0.41	0	0	0	0
1964	1.75	0	0	0	0	0	0
1965	3.52	3.10	2.09	0	0	0.74	0
1966	4.00	1.60	1.93	0	0	0	0
1967	4.00	2.18	0	0	0	0.40	0.25
1968	1.01	0	0	0	0	0	0

TABLE 13

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR CHAPLIN

4 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1921	1.70	0.29	0	0	0	2.18	2.01
1922	3.88	3.67	0	0	0	0	0
1923	1.78	0.60	0.04	0	0	0	0
1924	4.00	2.65	3.36	0.12	0	0	0.41
1925	2.18	0.43	0	0	0	0	0.23
1926	1.00	0.33	0	0	0	0.19	0
1927	3.74	4.00	0.60	0	0	0	0.13
1928	2.36	0	2.03	0	0	0	0.03
1929	1.86	0.98	0	0	0	0	0
1930	2.63	0.81	0	0	0	0	1.12
1931	0.59	0	0	0	0	0	0
1932	1.59	0	0	0	0	0	1.37
1933	2.27	1.40	0	0	0	0	0
1934	2.07	0	0.78	0	0	0	0
1395	2.40	2.08	1.51	0	0	0	0
1936	3.71	2.39	0	0	0	0	0
1937	1.09	0	0	0	0	0	0
1938	3.26	2.67	0	0	0	0	0
1939	2.49	0.51	1.60	0	0	0	0.25
1940	3.73	1.10	0	0	0	0	0
1941	2.66	0.71	0	0	0	0	0
1942	4.00	1.89	3.48	0	0	0	0
1943	2.56	3.10	0.39	0	0	0	0.78
1944	2.53	2.12	1.43	0	0	0	0
1945	3.16	1.40	0	0	0	0.35	0.25
1946	1.53	0	0	0	0	0	0.70
1947	4.00	2.35	3.49	0	0	0	0
1948	4.00	1.18	0	0	0	0	0
1949	0	0	0	0	0	0	0.94
1950	3.86	2.43	0	0	0	0	0
1951	3.15	0	1.25	0	0.34	0.33	0.39
1952	0.60	0	0	0	0	0	0
1953	3.19	3.55	4.00	0	0	0	0
1954	1.63	1.25	0	0	0.48	0.61	0
1955	2.12	2.05	0	0	0	0	0.92
1956	3.56	1.62	0	0	0	0	0
1957	2.15	0	0	0	0	0	0.34
1958	3.11	0	0	0	0	0	0
1959	1.42	0	0	0	0	1.57	2.64
1960	3.61	1.92	2.56	0	0	0	0
1961	3.11	1.16	0	0	0	0	0.26
1962	2.29	0.69	0	0	1.01	0	0
1963	0.70	0.21	3.24	0	0	0	0
1964	1.42	0	0	0	0	0	0
1965	3.74	4.00	2.29	0	0	0.65	0
1966	4.00	1.32	0.08	0	0	0	0

TABLE 14

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR GRAVELBOURG

4 inch Moisture Holding Capacity of Soil

Year	April	May	June	July (in inches)	Aug.	Sept.	Oct.
1928	1.08	0	0	0	0	0	0
1929	1.97	0	0	0	0	0	0
1930	3.63	1.69	0	0	0	0	0.67
1931	1.19	0	0	0	0	0	0
1932	3.22	0.31	0	0	0.71	0	0.35
1933	2.42	2.13	0	0	0	0	0.25
1934	2.11	0	0.21	0	0	0	0
1935	3.33	4.00	1.96	0	0	0	0
1936	4.00	2.71	0	0	0	0	0
1937	1.59	0	0	0	0	0	0
1938	3.18	2.01	0	0	0	0	0
1939	1.88	0.72	2.80	0	0	0	0
1940	3.68	1.08	0.11	0	0	0	0
1941	2.64	1.46	0	0	0	0	0
1942	4.00	2.79	3.77	0.04	0	0	0
1943	2.47	2.47	1.05	0	0	0	0
1944	0.69	1.45	0.07	0	0	0	0
1945	4.00	1.81	0	0	0	0	0
1946	0	0	0	0	0	0	0.43
1947	3.12	1.90	2.19	0	0	0	0
1948	4.00	0.97	0	0	0	0	0
1949	1.93	0	0	0	0	0	0.22
1950	4.00	2.33	3.13	0.47	0	0	0
1951	4.00	0.63	1.10	0	0.42	0	0.53
1952	1.95	0	0	0	0	0	0
1953	4.00	4.00	2.70	0	0	0	0
1954	3.88	3.80	3.46	0	0.82	1.36	0.40
1955	2.95	4.00	0.71	0	0	0	0
1956	2.28	0.72	0	0	0	0	0
1957	3.06	0	0	0	0	0	0.27
1958	2.79	0	0	0	0	0	0
1959	3.11	1.12	0.84	0	0	0	0.71
1960	2.93	1.14	2.69	0	0	0	0
1961	3.05	1.56	0	0	0	0	0
1962	0.27	0	0	0	0	0	0
1963	2.42	0.80	2.86	0.06	0	0	0
1964	1.64	0	0	0	0	0	0
1965	3.39	2.88	1.46	0	0	1.15	0
1966	3.87	1.95	0	0	0	0	0
1967	4.00	1.62	0	0	0	0.40	0.32
1968	1.37	0	0	0	0	0	0

The soil moisture retained in the soil at end of each month for the growing season, April to October, is tabulated in Table 12, 13, 14 and Appendix I.

The maximum amount of soil moisture retained in the basin is always at the end of March or April. Moisture levels do not reach the 4 inches capacity in over half of the years studied. In May, the average moisture retained becomes smaller as the average evapotranspiration increases more rapidly than average precipitation. Soil moisture retention may be high in June, which is the month of the heaviest rainfall. Soil moisture reserves are the lowest in July and August. In these months the evapotranspiration potential and the consumptive use factor[5] reach a maximum. Serious droughts occur frequently in these months.

Water Deficit Patterns

Water deficits and drought conditions occur whenever the soil moisture is depleted towards zero or AE is substantially less than PE. The calculated deficit is far more meaningful than direct interpretation of rainfall records (Laycock, 1967). The frequency of deficit will depend on the rainfall regime and the PE demands. Annual water deficit in the basin averages about 9 inches, ranging from 7.6 inches at Shaunavon to 9.9 inches at Shamrock (Figure 9). Water deficit has a great variation from year to year (Table 15, 17, 18, 19 and Appendix II). The highest value of deficit, for instance, was 16.36

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5. The consumptive use factor is the ratio of consumptive-use-for-crop-growth to PE.

MEAN ANNUAL WATER DEFICIT FOR 4 INCH MOISTURE HOLDING CAPACITY, JOHNSTONE LAKE BASIN, 1921-1968

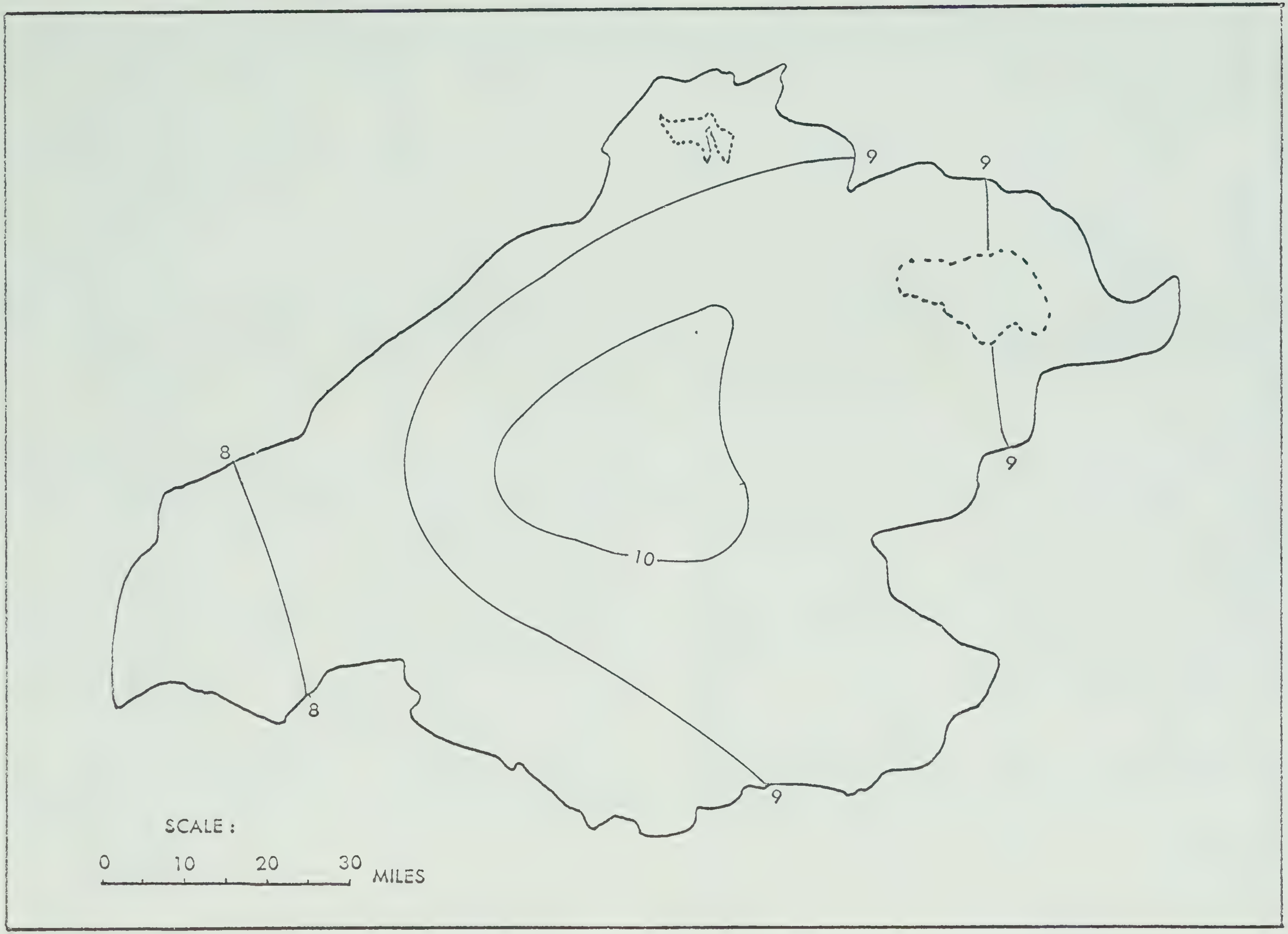


FIGURE 9

TABLE 15: WATER DEFICIT PATTERNS FOR THE SELECTED STATIONS.

Station	Period	Mean (in.)	Maximum (in.)	Minimum (in.)	S D (in.)	Coe. of Var. (%)
Aneroid	1923-68	9.69	16.36	0.34	3.43	35.4
Chaplin	1921-66	8.87	15.68	1.61	3.33	37.5
Gravelbourg	1928-68	9.49	15.63	0	3.46	36.5

inches and the lowest was 0.34 inches at Aneroid. In 1954, one of the wettest years in the area, Aneroid had a deficit of only 2.34 inches, Chaplin 1.61 inches, and Gravelbourg had no deficit. In 1936 and 1937, successive dry years resulted in an excessively high water deficit (Table 16), causing damage to grasses and trees, and widespread crop failure.

TABLE 16: WATER DEFICIT IN SUCCESSIVE DRY YEARS, 1936 AND 1937.

Year	Water Deficit for 4-inch Soil Moisture Holding Capacity		
	Aneroid	Chaplin (in inches)	Gravelbourg
1936	15.10	12.05	10.76
1937	15.62	15.68	14.90

It is known that severe drought can affect broad regions in certain years and the resulting demand for only limited supplies of irrigation water can be very large in such years. The timing and duration of the

TABLE 17

CLIMATIC WATER BALANCE FOR ANEROID 1923-1968

4 inch Moisture Holding Capacity of Soil

	Ppt.	=	(PE	-	Deficit)	+	Surplus	±	St. Change
			(in inches)						
1923	17.77	=	(21.98	-	5.05)	+	0.84	+	0
1924	13.80	=	(20.33	-	8.27)	+	0	+	1.74
1925	14.87	=	(21.01	-	7.76)	+	0.98	+	0.64
1926	14.36	=	(21.55	-	6.81)	+	1.05	-	1.43
1927	18.53	=	(21.91	-	6.42)	+	3.19	-	0.15
1928	11.80	=	(21.10	-	8.51)	+	0	-	0.79
1929	9.80	=	(21.40	-	12.94)	+	0	+	1.34
1930	11.64	=	(22.66	-	9.88)	+	0	-	1.14
1931	8.28	=	(22.95	-	14.98)	+	0	+	0.31
1932	12.93	=	(22.75	-	9.67)	+	0	-	0.15
1933	13.53	=	(22.34	-	9.68)	+	0	+	0.87
1934	10.78	=	(22.52	-	10.93)	+	0	-	0.81
1935	13.83	=	(21.81	-	7.69)	+	0	-	1.29
1936	8.80	=	(23.89	-	15.10)	+	0	+	0.01
1937	9.53	=	(24.76	-	15.62)	+	0	+	0.39
1938	15.67	=	(23.29	-	7.84)	+	0.31	-	0.09
1939	15.05	=	(22.12	-	7.21)	+	0.43	-	0.29
1940	16.51	=	(22.35	-	8.48)	+	2.02	+	0.62
1941	11.25	=	(22.64	-	11.92)	+	0	+	0.53
1942	22.28	=	(21.88	-	0.34)	+	0.61	+	0.13
1943	13.27	=	(22.21	-	8.26)	+	0.10	-	0.78
1944	9.52	=	(22.22	-	12.29)	+	0	-	0.41
1945	12.25	=	(20.24	-	9.07)	+	0	+	1.08
1946	10.70	=	(22.12	-	12.25)	+	0	+	0.83
1947	13.66	=	(21.96	-	6.81)	+	0	-	1.49
1948	12.41	=	(22.47	-	10.95)	+	0.19	+	0.70
1949	7.19	=	(23.98	-	16.36)	+	0	-	0.43
1950	13.03	=	(21.27	-	8.84)	+	0.74	-	0.14
1951	15.21	=	(20.20	-	6.75)	+	1.35	+	0.41
1952	15.36	=	(21.95	-	7.67)	+	2.16	-	1.08
1953	16.29	=	(21.56	-	8.67)	+	3.58	-	0.18
1954	21.52	=	(20.40	-	2.34)	+	3.71	-	0.25
1955	15.92	=	(22.29	-	6.86)	+	0	+	0.49
1956	8.16	=	(21.72	-	13.60)	+	0	+	0.04
1957	10.15	=	(21.62	-	11.47)	+	0	+	0
1958	10.76	=	(22.78	-	12.40)	+	0	+	0.38
1959	8.76	=	(21.26	-	11.99)	+	0	-	0.51
1960	9.28	=	(22.40	-	14.17)	+	0	+	1.05
1961	7.35	=	(21.77	-	13.88)	+	0	-	0.54
1962	14.88	=	(23.17	-	7.80)	+	0.37	-	0.86
1963	12.52	=	(24.00	-	12.15)	+	0	+	0.67
1964	11.60	=	(22.14	-	11.58)	+	0	+	1.04
1965	18.13	=	(21.38	-	3.96)	+	0.57	+	0.14
1966	13.50	=	(21.37	-	8.02)	+	0.87	-	0.72
1967	14.35	=	(20.56	-	10.30)	+	3.80	+	0.29
1968	9.17	=	(21.95	-	12.14)	+	0	-	0.64
Average	12.95	=	(22.05	-	9.69)	+	0.58	+	0.01

TABLE 18

CLIMATIC WATER BALANCE FOR CHAPLIN 1921-1966

4 inch Moisture Holding Capacity of Soil

	Ppt.	=	(PE	-	Deficit) (in inches)	+	Surplus	±	St. Change
1921	15.91	=	(22.55	-	8.87)	+	0	+	2.23
1922	10.95	=	(21.71	-	8.88)	+	0.13	-	2.01
1923	15.72	=	(21.08	-	6.23)	+	0	+	0.87
1924	18.12	=	(20.33	-	3.13)	+	0.68	+	0.24
1925	11.35	=	(21.61	-	8.86)	+	0	-	1.40
1926	14.16	=	(21.67	-	9.10)	+	0	+	1.59
1927	21.11	=	(21.31	-	4.04)	+	4.46	-	0.62
1928	11.68	=	(20.67	-	7.64)	+	0	-	1.35
1929	8.49	=	(21.81	-	15.27)	+	0	+	1.95
1930	10.93	=	(22.76	-	11.17)	+	0	-	0.66
1931	9.05	=	(22.55	-	12.78)	+	0	-	0.72
1932	17.47	=	(22.16	-	5.91)	+	0	+	1.22
1933	12.36	=	(22.23	-	9.52)	+	0	-	0.35
1934	10.05	=	(22.27	-	10.78)	+	0	-	1.44
1935	15.35	=	(21.23	-	7.54)	+	0	+	1.66
1936	10.23	=	(22.47	-	12.05)	+	0.63	-	0.82
1937	8.01	=	(23.78	-	15.68)	+	0	-	0.09
1938	12.65	=	(22.67	-	10.99)	+	0	+	0.97
1939	11.14	=	(21.98	-	10.13)	+	0	-	0.71
1940	11.85	=	(23.08	-	11.87)	+	0	+	0.64
1941	12.54	=	(22.73	-	9.81)	+	0	-	0.38
1942	18.13	=	(21.73	-	4.79)	+	0.51	+	0.68
1943	15.68	=	(21.25	-	5.45)	+	0.38	-	0.50
1944	13.02	=	(22.31	-	7.93)	+	0	-	1.30
1945	11.63	=	(20.43	-	9.87)	+	0	+	1.07
1946	15.38	=	(22.28	-	9.54)	+	0	+	2.64
1947	16.09	=	(22.05	-	3.54)	+	0.46	-	2.88
1948	11.87	=	(21.89	-	11.09)	+	0.33	+	0.74
1949	8.05	=	(23.21	-	14.50)	+	0	-	0.66
1950	13.55	=	(21.34	-	6.98)	+	0	-	0.81
1951	17.14	=	(19.86	-	3.59)	+	0	+	0.87
1952	10.58	=	(22.73	-	11.33)	+	0	-	0.82
1953	14.98	=	(21.79	-	7.01)	+	0.15	+	0.05
1954	19.16	=	(21.09	-	1.61)	+	0	-	0.32
1955	16.79	=	(22.42	-	7.97)	+	0	+	2.34
1956	9.52	=	(21.51	-	11.00)	+	0	-	0.99
1957	10.93	=	(22.43	-	12.47)	+	0	+	0.97
1958	10.69	=	(22.09	-	10.42)	+	0	-	0.98
1959	16.82	=	(21.69	-	8.26)	+	0	+	2.49
1960	10.81	=	(23.24	-	10.09)	+	0.63	-	2.97
1961	10.09	=	(22.83	-	13.61)	+	0	+	0.87
1962	16.83	=	(22.60	-	4.27)	+	0	-	1.50
1963	17.09	=	(23.21	-	6.39)	+	0	+	0.27
1964	11.53	=	(22.55	-	12.77)	+	0	+	1.75
1965	17.57	=	(21.79	-	6.13)	+	1.51	+	0.40
1966	15.13	=	(21.37	-	7.36)	+	2.44	-	1.32
Average	13.39	=	(22.01	-	8.87)	+	0.27	-	0.02

TABLE 19

CLIMATIC WATER BALANCE FOR GRAVELBOURG 1928-1968

4 inch Moisture Holding Capacity of Soil

	Ppt.	=	(PE	-	Deficit) (in inches)	+	Surplus	±	St. Change
1928	7.67	=	(22.46	-	14.79)	+	0	+	0
1929	11.47	=	(22.37	-	15.63)	+	0	+	4.76
1930	10.91	=	(22.09	-	10.03)	+	2.76	-	1.65
1931	10.35	=	(22.90	-	13.32)	+	0	+	0.77
1932	15.12	=	(21.72	-	6.95)	+	0.69	-	0.34
1933	11.95	=	(21.71	-	10.16)	+	0	+	0.40
1934	9.96	=	(22.21	-	10.85)	+	0	-	1.40
1935	14.90	=	(21.37	-	7.53)	+	0.81	+	0.25
1936	12.16	=	(22.46	-	10.76)	+	0.51	-	0.05
1937	7.85	=	(23.00	-	14.90)	+	0	-	0.25
1938	15.62	=	(22.95	-	8.58)	+	0.86	+	0.39
1939	12.81	=	(21.89	-	8.64)	+	0	-	0.44
1940	12.80	=	(23.08	-	11.26)	+	0	+	0.98
1941	14.71	=	(22.23	-	7.54)	+	0	+	0.02
1942	19.70	=	(20.17	-	2.08)	+	1.46	+	0.15
1943	12.85	=	(22.15	-	9.22)	+	0.92	-	1.00
1944	14.74	=	(21.81	-	7.57)	+	0	+	0.50
1945	10.85	=	(20.30	-	10.70)	+	1.61	-	0.36
1946	14.91	=	(22.50	-	10.33)	+	0	+	2.74
1947	12.88	=	(22.57	-	7.59)	+	0.38	-	2.48
1948	13.42	=	(22.94	-	12.05)	+	0.10	+	2.43
1949	8.53	=	(24.16	-	13.85)	+	0.05	-	1.73
1950	16.81	=	(20.52	-	4.36)	+	1.25	-	0.60
1951	21.46	=	(20.10	-	3.23)	+	3.79	+	0.80
1952	12.58	=	(21.95	-	8.36)	+	0.76	-	1.77
1953	13.92	=	(22.20	-	9.94)	+	1.52	+	0.14
1954	20.38	=	(20.41	-	0)	+	0	-	0.03
1955	15.52	=	(22.49	-	8.23)	+	0.20	+	1.06
1956	11.27	=	(21.85	-	10.54)	+	0	-	0.04
1957	10.80	=	(22.78	-	11.82)	+	0	-	0.16
1958	11.45	=	(22.87	-	11.89)	+	0	+	0.47
1959	15.47	=	(22.76	-	8.17)	+	0	+	0.88
1960	13.69	=	(23.60	-	9.52)	+	0	-	0.39
1961	7.71	=	(23.13	-	14.25)	+	0	-	1.27
1962	14.39	=	(23.56	-	8.74)	+	0	-	0.43
1963	15.57	=	(23.65	-	8.03)	+	0	-	0.05
1964	12.71	=	(23.60	-	12.31)	+	0	+	1.42
1965	18.54	=	(21.79	-	3.00)	+	0	-	0.25
1966	11.23	=	(21.78	-	9.69)	+	0	-	0.86
1967	13.02	=	(21.69	-	10.51)	+	0.75	+	1.09
1968	10.16	=	(22.98	-	12.11)	+	0	-	0.71
Average	13.24		(22.28	-	9.49)	+	0.45	+	0

drought are as yet unpredictable variables. In general, the largest deficits in the basin occur in July and August (Figure 5,6 and 7) when the daily rates of water use for crops reach the maximum for the growing season (Hobbs and Krogman, 1967).

Water Surplus Patterns

Ability to estimate the amount of surplus water is of considerable practical importance to the farmers. In the computation of the climatic water balance, the water surplus is the total amount of water available for surface runoff and deep percolation. So long as the soil moisture remains at the water holding capacity, any precipitation in excess of PE is counted as moisture surplus. The mean annual water surplus in the basin ranges from 0.26 inch at Chaplin to 1.80 inches at Instow. Naturally, the area with the highest surplus is the Cypress Hills region where precipitation is higher, especially snowfall, and PE is lower. In contrast, the lowest surplus occurs in the Chaplin Lake region where PE is high and snowfall is lowest.

The greatest surplus occurs in the spring months of March or April. In March of most years precipitation exceeds PE in most areas in the basin. Heavy snowfall is occasionally received and this contributes to a large surplus, especially in the Cypress Hills region. In 1967, for example, Instow had 9.04 inches of water surplus, Shaunavon 5.84 inches, and Aneroid 3.80 inches. In May, June, July and August as the PE increases more rapidly than precipitation, surpluses are very infrequent in most parts of the basin. Occasionally heavy rainfall contributes more to soil moisture recharge than to runoff, except in a particularly wet year.

In September of most years, PE still exceeds precipitation, and water surpluses are almost wholly absent in the basin. In October, precipitation sometimes exceeds PE and most of this moisture enters into soil moisture storage.

In November to February the mean monthly temperature generally is below 32°F., thus the potential surpluses are largely detained upon the surface as snow and may last until spring before contributing to soil moisture recharge or runoff. In practice, evaporation and sublimation reduce a part of this moisture in the basin (Appendix III) (Laycock, 1967; McKay, 1962).

CHAPTER III

WATER MOVEMENT CHARACTERISTICS OF THE JOHNSTONE LAKE BASIN

Streamflow Patterns

Streamflow refers to the total runoff in stream channels from a drainage basin. Annual streamflow refers to all types of runoff taking place within the period of one year from a drainage basin. The detail with which streamflow may be investigated depends upon the availability of pertinent information. In the Johnstone Lake basin, hydrologic records have been kept since 1914 (Appendix IV). The most complete records are those made on Notukeu Creek near Vanguard. Hydrologic records are available for 1914-1922 inclusive, for 1940, and continuously from 1944 to the present. Unfortunately, the water level record in the lake is so incomplete that comparing the water balance calculations with streamflow records is made difficult.

The gross drainage area of the Wood River is about 5,000 square miles. Due to a great deal of depressional storage in most of the watersheds, the 5,000 square miles gross drainage area has an effective drainage area of only 2,707 square miles (Figure 10 and Table 20) (Godwin, 1961; Jansson, 1968; Freeze, 1969a). The average annual runoff ranges from 0.53 to 0.67 inch for effective drainage area of the streamflow gauging station in the Johnstone Lake basin. The median annual runoff for the period 1911-1950 for the entire Wood River basin was 76,000 acre-feet (Godwin, 1961).

STREAM GAUGING STATIONS AND THEIR EFFECTIVE DRAINAGE AREAS, JOHNSTONE LAKE BASIN

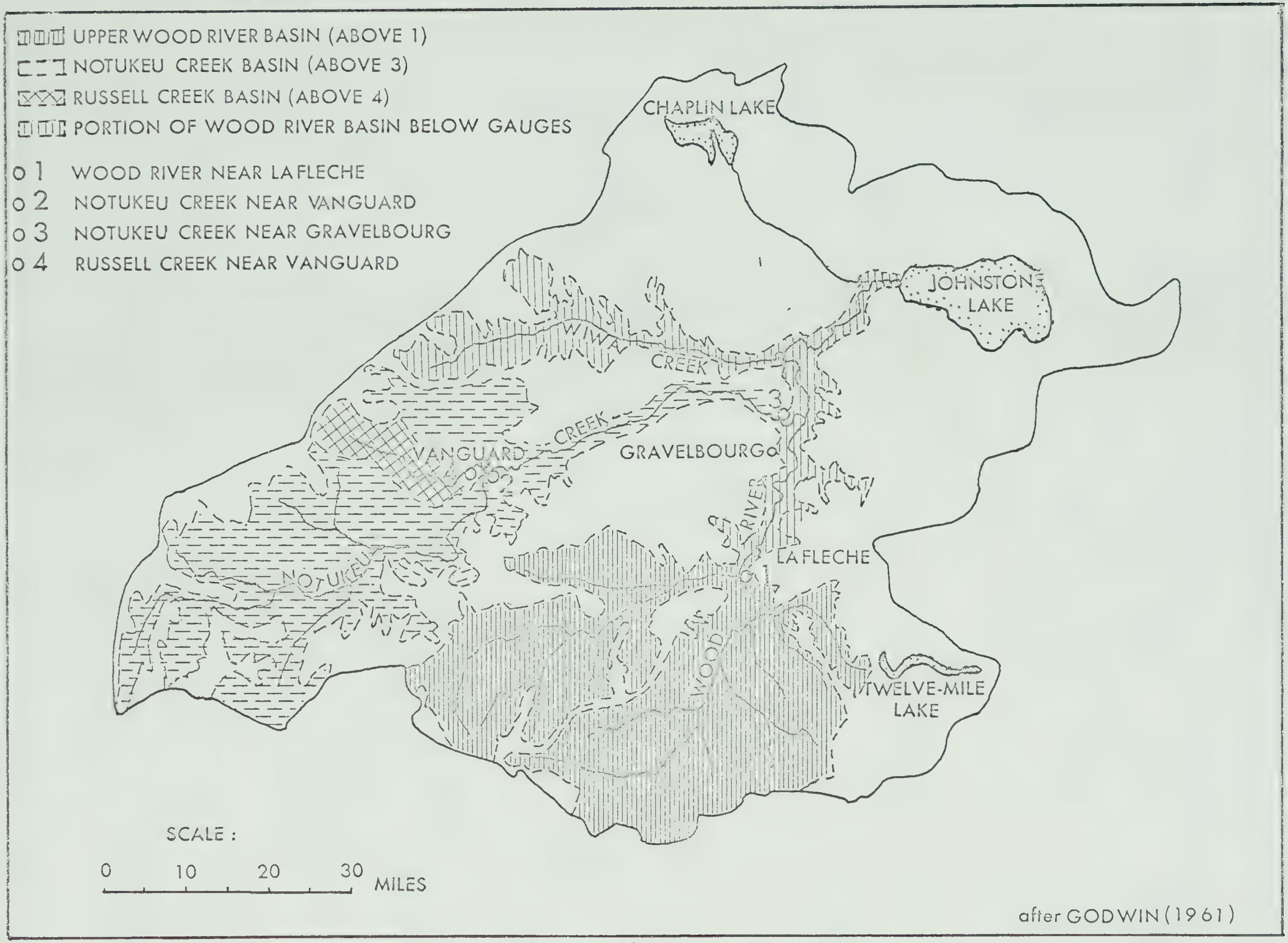


FIGURE 10

TABLE 20: SUMMARY OF SURFACE RUNOFF, JOHNSTONE LAKE BASIN

Stream Gauging Station	Effective drainage area (E.D.A.), sq.mi.	1944-1968 Average annual runoff, acre-feet	inches E.D.A.	1951-1964 Average annual baseflow* acre-feet	inches E.D.A.
Wood River near La Fleche	1,252	43,244	0.65	2,560	0.038
Notukeu Creek near Vanguard	945	31,730	0.63	3,500	0.069
Notukeu Creek near Gravelbourg	1,030	29,442	0.53	2,800	0.051
Russell Creek near Vanguard	108	3,879	0.67	171	0.030
Wood River drainage basin	2,707	76,000**	0.53		
		96,000***	0.66		

* after Freeze, 1969a.
** Median annual runoff, 1911-1950 (after Godwin, 1961).
*** Median annual runoff, 1911-1950, plus " Consumptive Use " within effective drainage area (after data of Godwin, 1961 and Freeze, 1969a).

There is a great variety of hydrological regimes from year to year on the rivers of the basin (Table 21). For all rivers, the coefficient of variation is over 70 per cent. At the Wood River near La Fleche, it is over one hundred per cent. This is one of the problems for consideration of water demand and water supply.

A characteristic of flow for all streams of the Johnstone Lake basin is one of the wide variability in discharge during various periods of the year. A great part of the total runoff occurs within a relatively short period of time due to intensive water inflow from

TABLE 21: ANNUAL RUNOFF PATTERNS IN THE JOHNSTONE LAKE BASIN, 1944-68.

Stream Gauging Station	Annual Runoff Patterns Mean ac-ft	Maximum ac-ft	Minimum ac-ft	S D ac-ft	Coef. of Var. (%)
Wood River near La Fleche	43,244	209,800	2,650	44,039	102
Notukeu Creek near Vanguard	31,730	144,600	1,920	30,914	97
Notukeu Creek near Gravelbourg	29,443	112,480	1,960	25,364	86
Russell Creek near Vanguard	3,879	13,720	436	2,888	74

snowmelt during spring (Figure 11). The contribution of snowmelt to rivers comprises about 90 per cent of the entire annual runoff in the basin. Consequently, the portion from rainfall is small. The drainage system is a simple plain snow regime[6] (Pardé, 1955).

The runoff patterns are strongly influenced by the temperature regime. During the spring, increasing air temperature and day length lead to melting of snow, which in turn produces water contributing to flooding and increased runoff. During the summer, the increased insolation increases the evapotranspiration, thus reducing surplus for

6. Pardé classified the rivers into three regimes: (1), simple regime, only one flow peak in a year, (2) original complex regime, two or three flow peaks in a year, (3) variable complex regime, in which a river has a wide drainage area and its water come from different sources. See M. Pardé, Fleuves et Riviéres, Librairie Armand Colin, Paris, 1955, p.80.

FIGURE 11

STREAM FLOW PATTERNS IN JOHNSTONE LAKE BASIN 1944-1968

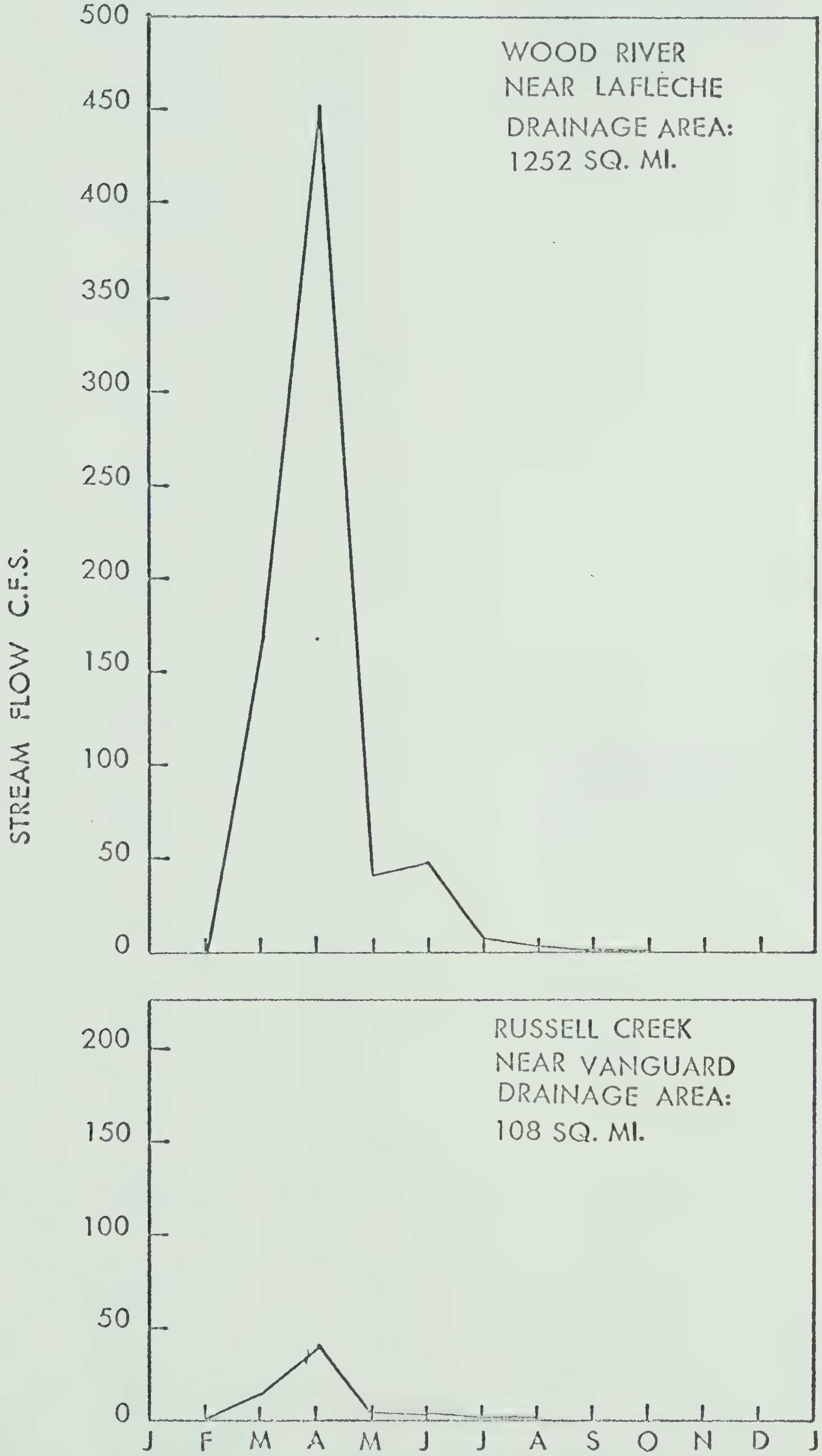
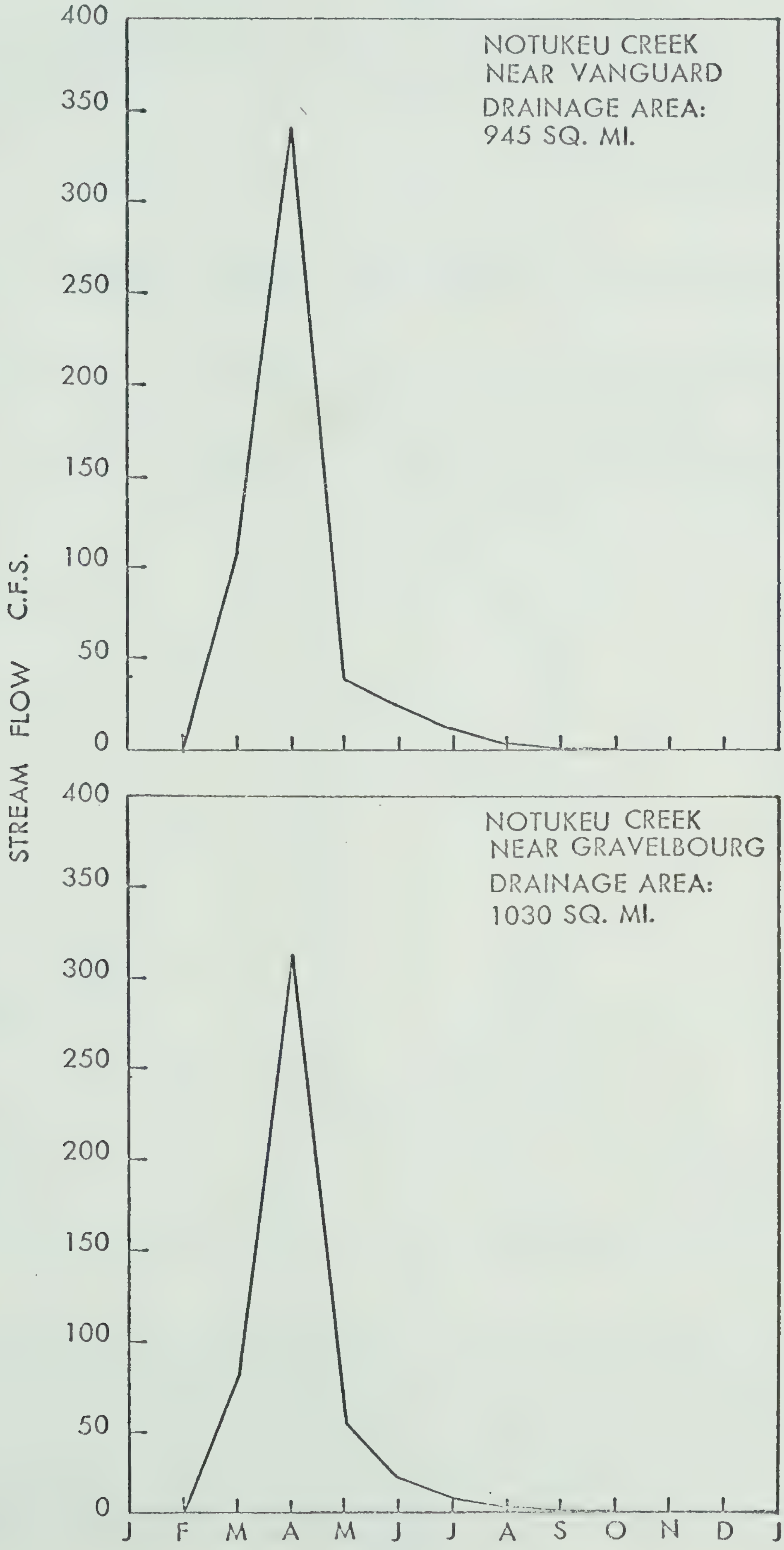


FIGURE 11

STREAM FLOW PATTERNS IN JOHNSTONE LAKE BASIN
1944-1968



runoff. The maximum flow occurs during April or March depending on the individual year (Figure 11). Sometimes there is another peak in June due to the early summer rainfall. In general there are two or three months during which the monthly discharge coefficient[7] exceeds 1.00, whereas in other months this value may tend towards zero (Table 22).

TABLE 22: MONTHLY DISCHARGE COEFFICIENT IN THE JOHNSTONE LAKE BASIN.

Station	Wood River near La Fleche	Notukeu Creek near Vanguard	Notukeu Creek near Gravelbourg	Russell Creek near Vanguard
January	0	0	0	0
February	0	0	0	0
March	2.84	2.46	1.96	2.71
April	7.47	7.40	7.90	7.40
May	0.71	0.77	1.29	0.77
June	0.81	0.68	0.51	0.68
July	0.11	0.23	0.21	0.23
August	0.05	0.11	0.17	0.11
September	0.01	0.06	0.03	0.06
October	0	0.03	0.03	0.03
November	0	0	0	0
December	0	0	0	0

Taking the period 1944-1968, the Wood River near La Fleche had a maximum monthly discharge of 3,472 c.f.s. in April of 1952, and a

7. Monthly discharge coefficient equals individual monthly discharge divided by mean monthly discharge.

minimum monthly discharge of 12.8 c.f.s. in April of 1961. The monthly discharge for June of 1962 was 328.0 c.f.s. apparently due to unusual local thunderstorms which boosted the monthly average value for June by 291.1 c.f.s.

The minimum monthly discharge is greater than zero for not more than four months of each year. Usually, it is for only two to three months. This sustained flow is considered to be the baseflow[8] (Table 20) (Freeze, 1969a).

The runoff records revealed an interesting phenomenon; it was the fact that the average annual stream loss from Notukeu Creek between Vanguard and Gravelbourg is 2,288 c.f.s. The apparent reasons for this are: (1) losses to phreatophytic growth along the stream channel, (2) losses to bank storage, and (3) losses due to the regional groundwater flow system (Godwin, 1961 and Freeze, 1969a). The same situation may occur in Pinto Creek and Wood River which traverse similar topographic, geologic, and hydrologic terrain (Freeze, 1969a).

Lake and Reservoirs

Measurements of lake level fluctuation in the basin are extremely scanty (Appendix IV). Godwin (1961) estimated that the water level of Johnstone Lake fluctuated from an elevation of 2,176 to 2,188 feet during the period 1923-1951 (Figure 12). When this lake level exceeds an elevation of 2,188 feet it begins to overflow northwestwards to Chaplin Lake. There has been no overflow since 1928. All the other lakes are shallow and large saline mud flats cover the valley (Table 23).

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8. Base flow, or base runoff, is defined as the sustained or fair-weather runoff. It is composed of groundwater runoff and delayed subsurface runoff.

FIGURE 12. ESTIMATED WATER LEVEL OF JOHNSTONE LAKE, 1923-1950

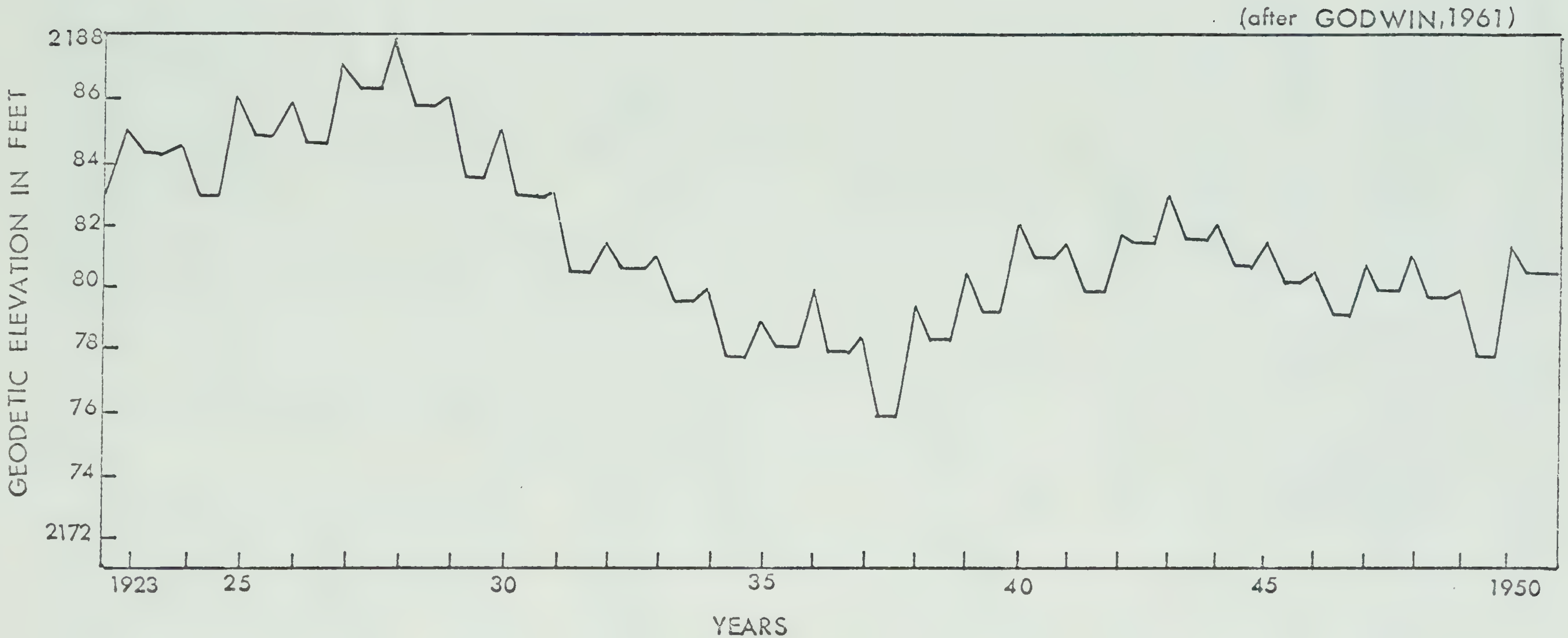

TABLE 23: HYDROLOGY OF LAKE IN THE JOHNSTONE LAKE BASIN.

Lake	Elevation, ft.a.s.l.	Overflow elevation, ft.a.s.l.	Area of lake, sq.mi.	Effective drainage area, sq.mi.	Depth, ft.	Salinity,* ppm.
Chaplin Lake	2,170	NW-none SE-2,188	20	300	10	47,893
Johnstone Lake	2,186	EW-2,188 SE-2,200	110	2,730	20	1,006
Twelve-Mile Lake	2,470	E- W- 2,472	9	166	10	906

* Salinity is the ratio of total solids to total sample of lake water.

Source: after Freeze (1969a).

TABLE 24: MAJOR RESERVOIRS IN THE JOHNSTONE LAKE BASIN.

Name	River basin	Storage Capacity in ac-ft	Surface Area in acres	Benefits	Year of Construction
Thomson	Wood River	30,000	2,300	Irrigation	1940
Gouverneur	Notukeu Creek	6,300	470	Irrigation	1949
Braddock	Wiwa Creek	1,600	154	Stock water Irrigation	1949
Russell Creek	Russell Creek	1,520	124	Irrigation	1951
Cadillac	Notukeu Creek	1,350	175	Irrigation	1945
Admiral	Notukeu Creek	980	96	Irrigation	1949

Sources: Godwin, 1961 and Annual Report of PFRA, 1947, 1950 and 1952.

Artifical reservoirs have been constructed in the basin (Table 24). The largest reservoir is the Thomson Reservoir which is located on the Wood River between Gravelbourg and La Fleche. It has a capacity of 30,000 acre-feet and a surface area of approximately 2,300 acres (Godwin, 1961). It is capable of supplying, without shortage, up to 6,500 acres with summer irrigation water. The storage capacity of other reservoirs ranges from 980 to 6,300 acre-feet. All reservoirs, except Russell Creek Reservoir, were completed in the 1940s.

Groundwater

Lack of rainfall during 1930 to 1934 over a large part of the Prairie Provinces brought about an acute shortage both in the supplies of surface water to be used for irrigation, and in the supplies of groundwater available for domestic purposes and watering stock. In 1936, in an effort to relieve the serious situation, the Canadian Geological Survey began an extensive study of the problem from the standpoint of domestic use and stock raising. This was the first survey of its kind in the basin. The results were published as a Water Supply Paper for each rural municipality. The Paper contains the well records and an interpretation of the groundwater conditions in each rural municipality.

The water table is usually less than 25 feet below the ground surface. The highest fluctuation of the water table levels was recorded from a 36-foot well in glacial till area; the depth to the water varied from 14.05 to 17.95 feet over the years, 1963-1965. This gives a fluctuation of 3.9 feet during the period (Freeze, 1969a).

According to the Water Supply Paper (1936), there is an area of flowing artesian wells in the vicinity of Gravelbourg. It is known as the Gravelbourg aquifer. The aquifer underlies an area of about 85 square miles northwest of Gravelbourg. Recharge to the lower strata of the drift material occurs through the glacial till of the southern and northern uplands and through the clay and till of the Gravelbourg plain. There are two areas of groundwater discharge: Wiwa Creek valley in the northern part, and a string of depressional sloughs along the southern edge of the Gravelbourg plain at the base of the southern upland. It is possible that underflow beneath Wiwa Creek through the silty clay phase of the lower strata of the drift transmits water northeast toward the Johnstone Lake. There is no evidence of groundwater discharge into Notukeu Creek or Wood River. The safe yield of the Gravelbourg aquifer may be considered to be 280 acre - feet/ year (Freeze, 1969b).

Another important area of groundwater recharge and discharge is in the Upper Notukeu Creek. Recharge of groundwater occurs in the upland of the Shaunavon Plateau where groundwater movement is essentially downward through the low-permeability glacial drift of the Ravenscrag Formation. The groundwater discharge areas were identified through the presence of alkali soils and a distinctive suite of alkali-tolerant vegetation. Seven flowing wells occur in association with the saline valleys (Freeze, 1969b), as evidence of groundwater discharge.

Because of the closed drainage of the basin, the intermittent streams and the intermittent depressional sloughs, rising groundwater is lost to the atmosphere by evapotranspiration during much of the year. This tends to concentrate salts in the soil, soil water and groundwater.

Because of the high degree of mineralization in groundwater, a constant supply of salt is contributed to the discharge area. As evapotranspiration occurs these are left behind as a saltcake. This process also accounts for the high degree of mineralization of permanent sloughs and lakes. Concentrations have become so high that deposition of sodium sulphate on the lake bottom has reached considerable proportions and the salt is being mined commercially. There is a sodium sulphate processing plant at Chaplin and one at Bishopric.

The Importance of Streamflow and Groundwater in Water Balance

Streamflow is an important variable of the water balance. It is an area measurement of water rather than a point observation which precipitation, evapotranspiration, or soil moisture at climatological stations are. It is a residual quantity of precipitation after evaporation and transpiration have taken their share and storage change has resulted. The runoff values derived from the calculations based on the Thornthwaite procedure will be correlated with the measured discharge in order to assess how accurately the procedure predicts discharge for the basin. The use of groundwater flow patterns can be an important tool in the determination of the basin-wide water balance (Freeze, 1967). Because the groundwater flow pattern must be in dynamic equilibrium with the other components of the hydrologic cycle, its configuration has an important effect on the quantity and areal concentration of such parameters as infiltration, evapotranspiration and surface runoff. The recharge-discharge profile of groundwater flow provides an insight into the areal variations in the values of these hydrologic parameters. For example, if one analyses the streamflow

records at several stream gauging stations in a basin, one will find that the baseflow varies along the length of stream, depending on the position of the gauging site in the recharge-discharge profile. The groundwater inflow to Johnstone Lake is an important stabilizing factor to variation of lake area, and this will be dealt with in Chapter IV.

CHAPTER IV

INTEGRATION OF THE CLIMATIC WATER BALANCE OF THE WATERSHED IN THE JOHNSTONE LAKE BASIN

Annual Runoff

The major water-yielding areas and the amounts of runoff in the basin in depth in inches are illustrated in Figure 13. Runoff computed for climatological stations in the basin was used for making maps of the distribution of the average annual runoff. The depth of runoff was determined by taking the area of each strip between successive isolines on the map, and multiplying by the average depth of runoff per strip. By this method the mean annual runoff was calculated from Figure 13 as 0.66 inch for the effective drainage area of Wood River. Conversion indicates that about 90,950 acre-feet of water emerge from the water-yielding areas in the Wood River and its tributaries. This value is in good agreement with those calculated by Godwin (1961) for the entire Wood River basin and with the measured runoff for the four stations in the Johnstone Lake basin (Table 20). Godwin estimated that the sum of the median annual runoff and water depletion due to consumptive use is 96,000 acre-feet, giving the depth of 0.66 inch for the effective drainage area. The depths of measured runoff are 0.65 inch for Wood River near La Fleche, 0.63 inch for Notukeu Creek near Vanguard, 0.53 inch for Notukeu Creek near Gravelbourg, and 0.67 inch for Russell Creek near Vanguard. For a period of 1951-1968, the measured and calculated runoff are compared for each year for each station (Table 25).

MEAN ANNUAL RUNOFF (IN INCHES), JOHNSTONE LAKE BASIN, 1921-1968

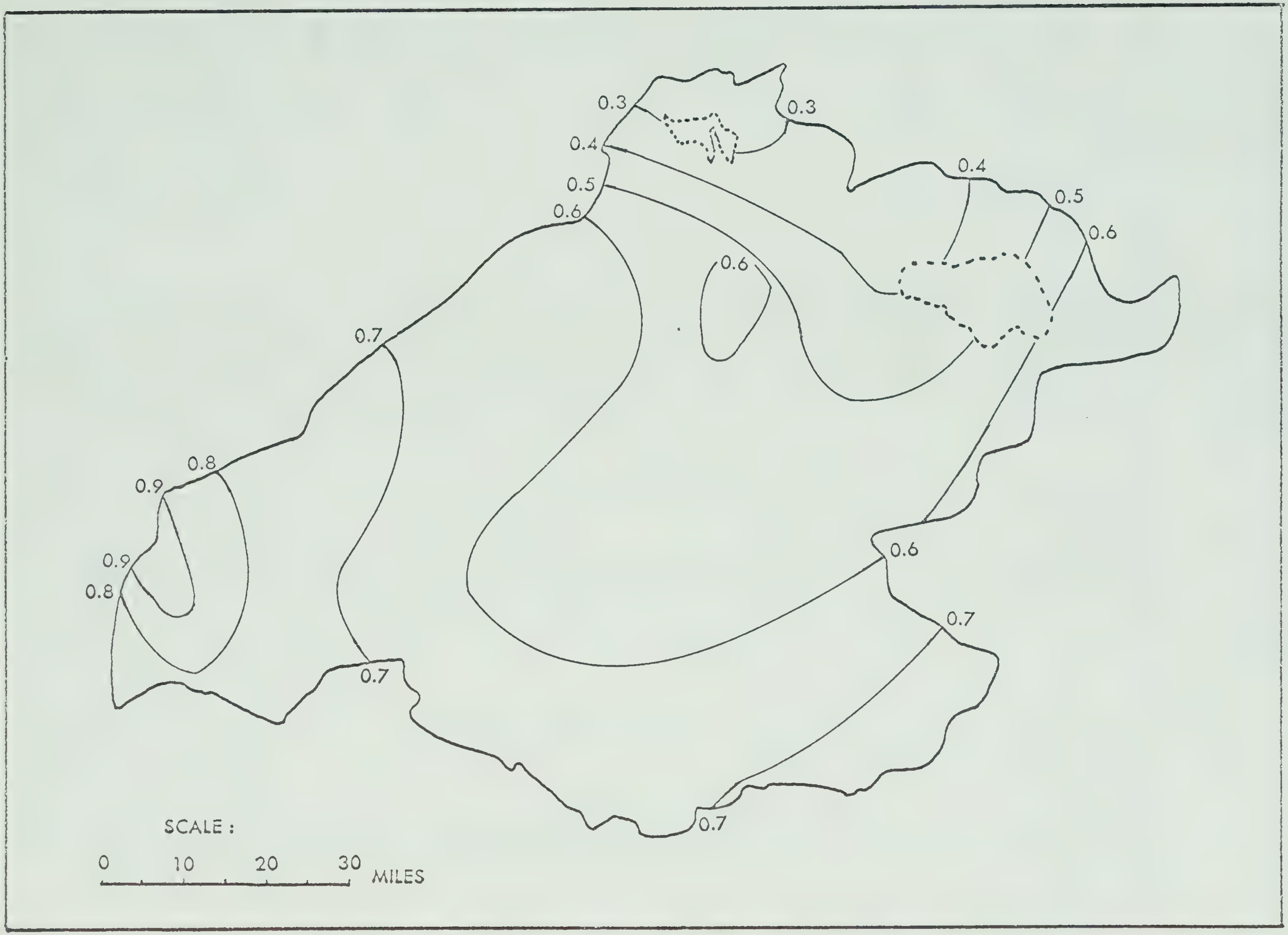

FIGURE 13

TABLE 25

ANNUAL COMPUTED AND MEASURED RUNOFF 1951-1968

(in inches)

Year	Wood River near LaFleche com.	Wood River near LaFleche mea.	Notukeu Creek near Vanguard com.	Notukeu Creek near Vanguard mea.	Notukeu Creek near Gravelbourg com.	Notukeu Creek near Gravelbourg mea.	Russell Creek near Vanguard com.	Russell Creek near Vanguard mea.
1951	2.07	1.17	1.27	1.17	1.90	1.12	1.36	0.97
1952	0.97	3.14	0.99	2.85	0.93	2.05	1.47	2.04
1953	2.29	1.15	2.53	1.06	2.28	0.89	2.90	0.96
1954	1.06	0.68	1.71	0.81	1.29	0.71	2.57	0.80
1955	0.28	1.25	0.52	1.20	0.44	1.04	0.46	0.87
1956	0	0.49	0	0.20	0	0.22	0	0.29
1957	0	0.07	0	0.33	0	0.26	0	0.36
1958	0	0.32	0	0.74	0	0.55	0	0.72
1959	0	0.22	0	0.10	0	0.08	0	0.11
1960	0	0.55	0.16	0.61	0.12	0.50	0.24	0.81
1961	0	0.06	0.19	0.13	0.14	0.10	0.28	0.06
1962	0.42	0.68	0.66	0.40	0.50	0.37	0.55	0.27
1963	0	0.32	0	0.26	0	0.34	0	0.30
1964	0.19	0.03	0.19	0.04	0.14	0.03	0	0.17
1965	0.60	0.65	0.92	0.85	0.69	0.60	0.75	0.74
1966	1.05	0.44	1.30	0.79	0.99	0.65	0.81	0.60
1967	3.46	1.26	4.61	1.32	3.64	1.26	4.00	0.80
1968	0	0.25	0	0.18	0	0.17	0	0.21

The correlation coefficient of the two variables is 0.48 for Wood River near La Fleche, 0.47 for Notukeu Creek near Vanguard, 0.61 for Notukeu Creek near Gravelbourg, and 0.49 for Russell Creek near Vanguard. Theoretically, the correlation coefficient at the 1 per cent level of statistical significance for this eighteen years of data is 0.5897; at the 5 per cent level it is 0.4683; at the 10 per cent level it is 0.4000. The correlation of two variables shows that they vary in similar manner.

The Rate of Snow Melt Runoff and Monthly Total Runoff

In the Thornthwaite procedure, there is an assumption that if the mean monthly air temperature is below 30.2°F., precipitation falls as snow. Applying this to this basin the first month when the temperature is above 30.2°F., snow starts to contribute to runoff. However, occurrence of snow and the rate of melt are defined by topoclimatic factors which may cause considerable deviation from the assumed patterns. Because snowmelt is the result of many different processes of heat transfer, the relative importance of the various heat transfer processes involved in the melting of snowpack must vary with time and with site. As a result, no single method or index for computing snowmelt is universally valid for all areas and for all times of the year.

The mean monthly temperature alone can not indicate the number of days or hours in the month when the temperature is low enough for the precipitation to fall as snow. Similar consideration applies to the rate of melt of snow once it has accumulated. The rate of snow melt can be different in different months even though the mean monthly temperatures are the same. Van Hylckama (1958) has illustrated this with data of December 1950 and January 1951 in the Delaware basin when

70 and 90 per cent respectively of the precipitation ran off although the mean monthly temperatures were respectively 24.2°F. and 25.6°F. It has been observed that the Thornthwaite method underestimates winter runoff and frequently errs in the month of maximum spring runoff (van Hylckama, 1956; Sanderson, 1966). Van Hylckama (1958) published a workable modification of the Thornthwaite method for estimating runoff in the Delaware Valley, and Sanderson (1966) did the same for the Lake Erie watershed. In this thesis, a relevant modification of the original water balance criterion is introduced so as to fit the conditions of winter and spring runoff within the Johnstone Lake basin. The basis for this modification is described later.

Much work has been done in relating snowmelt amounts to temperature indices (Collins, 1934; Garstka et al, 1958; U.S. Army, Corps of Engineers, 1956.). The most commonly used index is degree-days above freezing point, that is, the number of degrees in excess of 32°F. calculated from the mean daily temperature. However, degree-days calculated upon the daily maximum temperature rather than the mean daily temperature gave the best correlation with snow melting (Garstka et al, 1958; U.S. Army, Corps of Engineers, 1956). This seems more acceptable since most of the energy available for melting in either winter or spring will be concentrated into the day-light hours and in most instances will be reflected in the daily maximum temperature. In this thesis, it is felt that the rate of the snow melt runoff during the months with mean temperature less than 30.2°F. should not be considered to be zero. Snowmelt should correlate with degree-days based upon the daily maximum temperature. Sometimes, degree-days during the months with mean temperature less than 30.2°F. are over 200. In March of 1953, for

example, degree-days were 219 at Aneroid and 210 at Gravelbourg while mean monthly temperatures were 25.2°F. and 24.6°F., respectively.

Thornthwaite has shown too that for a large watershed, only about 50 per cent of the computed surplus water available for runoff in any month actually runs off, the remainder being held over as part of the surplus in the following month. This relation will naturally vary with local conditions, such as drainage area, slope, water holding capacity of soil, soil temperature, etc. In the Johnstone Lake basin, the snow cover is relatively shallow. Median depth of snow cover is below 8 inches on February 28 (Potter, 1965). Due to the flat terrain and lack of forest cover, melting occurs practically simultaneously over the entire drainage basin and melt rates are higher than in the mountain region. Both of these factors tend to produce high, sharp flood waves. Snowmelt floods last but a few days[9]. Flooding as a result of snowmelt does not occur every year. As a result of the preceding study of the relationship between measured runoff and calculated water surplus in the Johnstone Lake basin (see Figure 11 and 13), it has been found that most sub-basins drain the surplus water at a rate close to 75 per cent per month. The relationship too between the rate of snow melt runoff during months with mean temperature less than 30.2°F. and degree-days based on maximum daily temperature is shown in Table 26. These rates of runoff, as will be shown later, give a more satisfactory correlation between calculated and measured monthly total runoff.

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9. K. A. Johnson stated some melting generally occurs as a result of short warming periods during the winter months, the major portion of snowmelt occurs in a period of 10 days or less during late March or early April in the Missouri River basin. See U.S. Army, Corps of Engineers, Snow Hydrology , U.S. Department of Commerce, Office of Techenical Service, 1956, p.338.

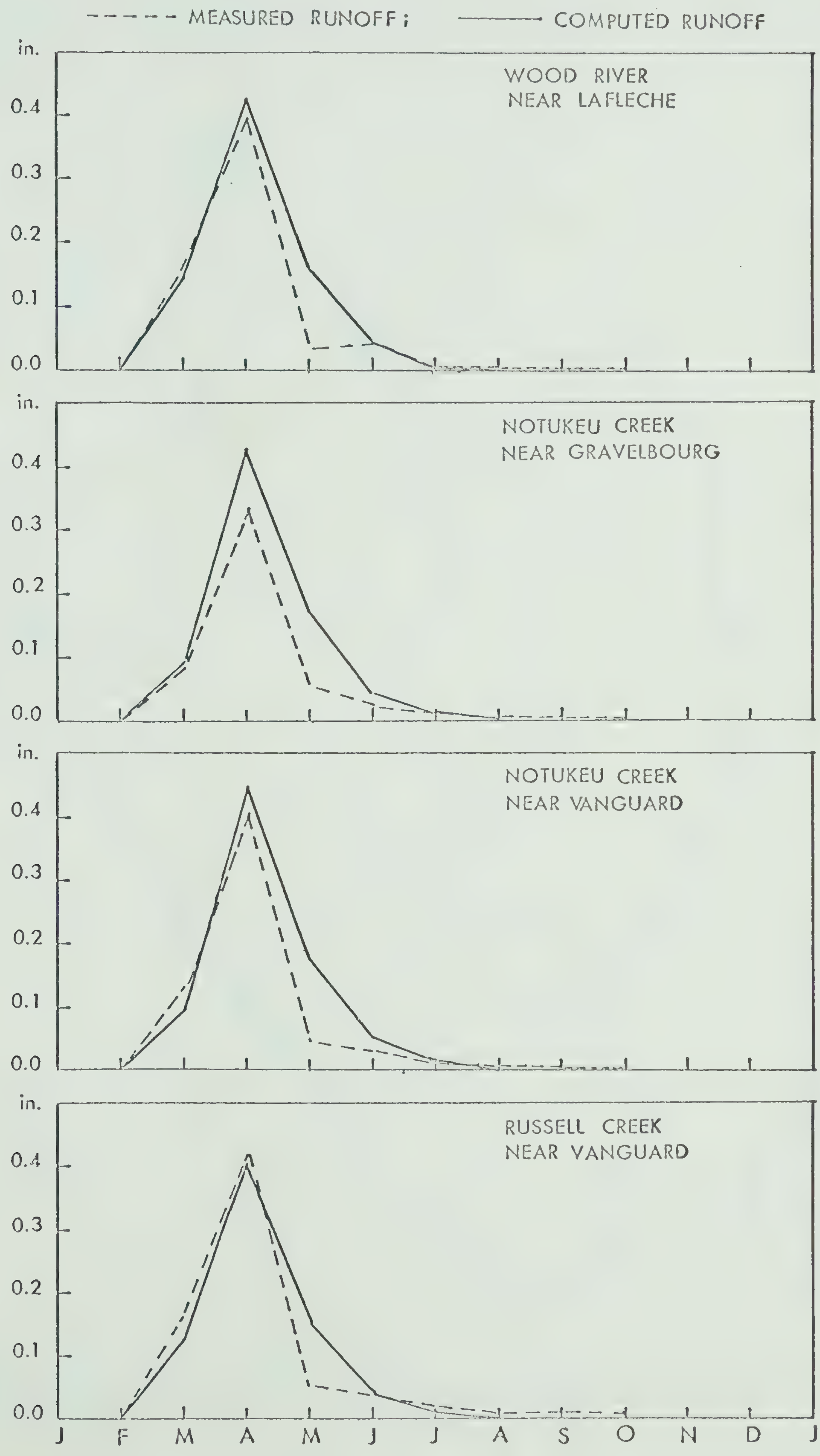
TABLE 26: THE RATE OF SNOW MELT RUNOFF DURING MONTHS WITH MEAN TEMPERATURE LESS THAN 30.2°F. AND DEGREE-DAYS BASED ON MAXIMUM DAILY TEMPERATURE.

Degree-days	<30	31-50	51-100	101-150	151-200	>200
Percentage of snow melt runoff in the month	0	10	20	40	60	75

Monthly Runoff Patterns

The distribution of average monthly runoff is shown in Figures 14, 15, 16, 17 and 18. Because of the low temperature and frozen conditions which prevail during November to February, no runoff occurs. As a rule, March is characterized by only partial snow melt. The rate of runoff can be assumed to vary with the rate of accumulation of energy as measured by degree-days in any one year. In practice computed March runoff is less than the measured. This seems due to the fact that the ground beneath the snowpack is often frozen. This condition encourages surface runoff during the period of snow melting before recharge to the level of moisture holding capacity of soil can be completed (U.S. Army, Corps of Engineers, 1956). Frequently the spring break-up comes in March, when the daily maximum air temperature may reach over 40°F. for a few days. Under such conditions, most of the snow disappears in 3 or 4 days and some runoff is inevitable even in a dry year when the soil is in the most favorable condition to absorb water. Rainfall that might occur during the period of snow melt increases the runoff to the river and the heat derived from rainfall is also an important factor in snow melt.

FIG. 14 MEAN MEASURED AND COMPUTED RUNOFF PATTERNS
JOHNSTONE LAKE BASIN, 1950-1968



MEAN MONTHLY RUNOFF (IN INCHES) IN MARCH , JOHNSTONE LAKE BASIN, 1944-1968

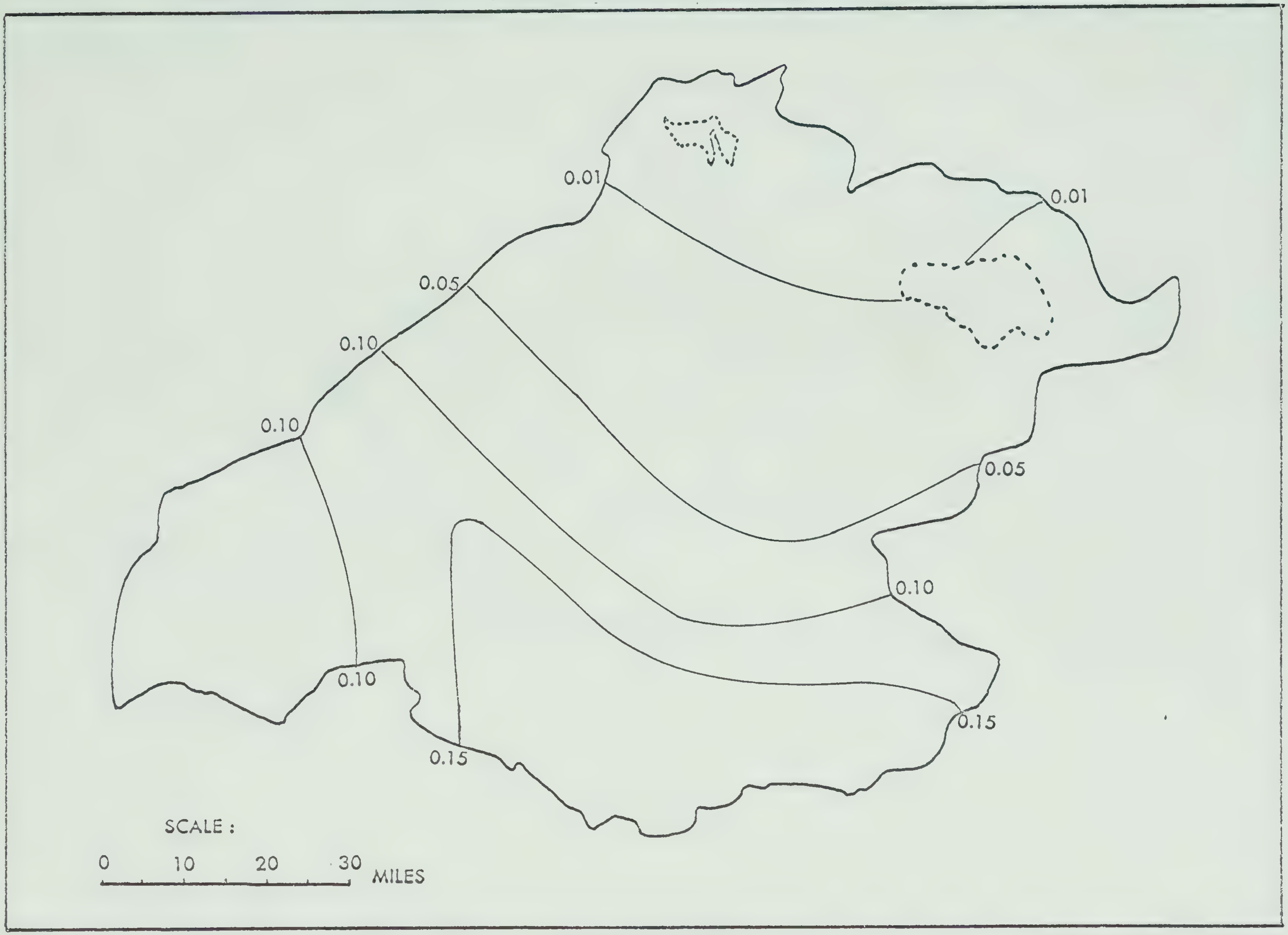


FIGURE 1 5

MEAN MONTHLY RUNOFF (IN INCHES) IN APRIL, JOHNSTONE LAKE BASIN, 1944–1968

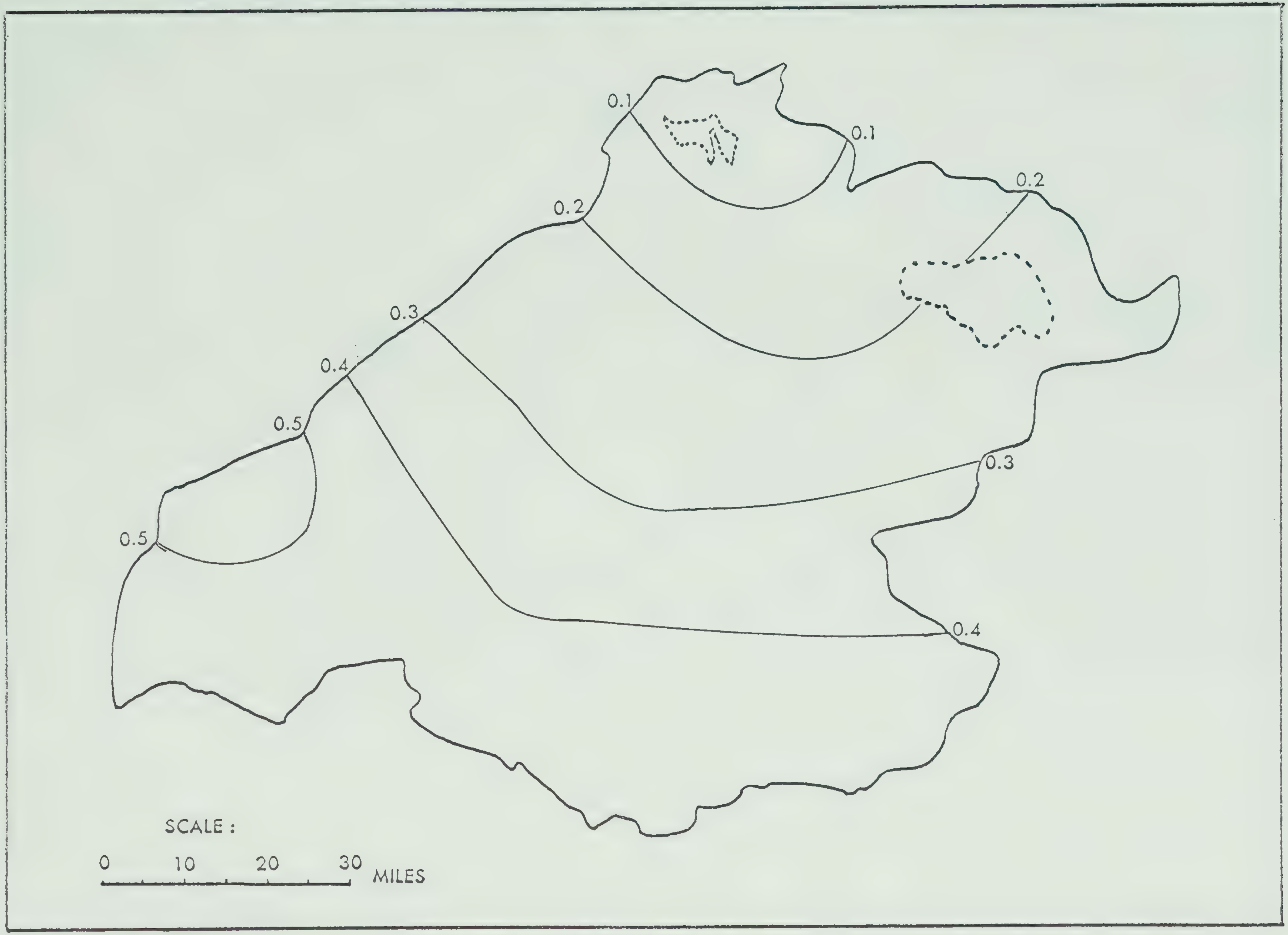


FIGURE 16

MEAN MONTHLY RUNOFF (IN INCHES) IN MAY, JOHNSTONE LAKE BASIN, 1944-1968

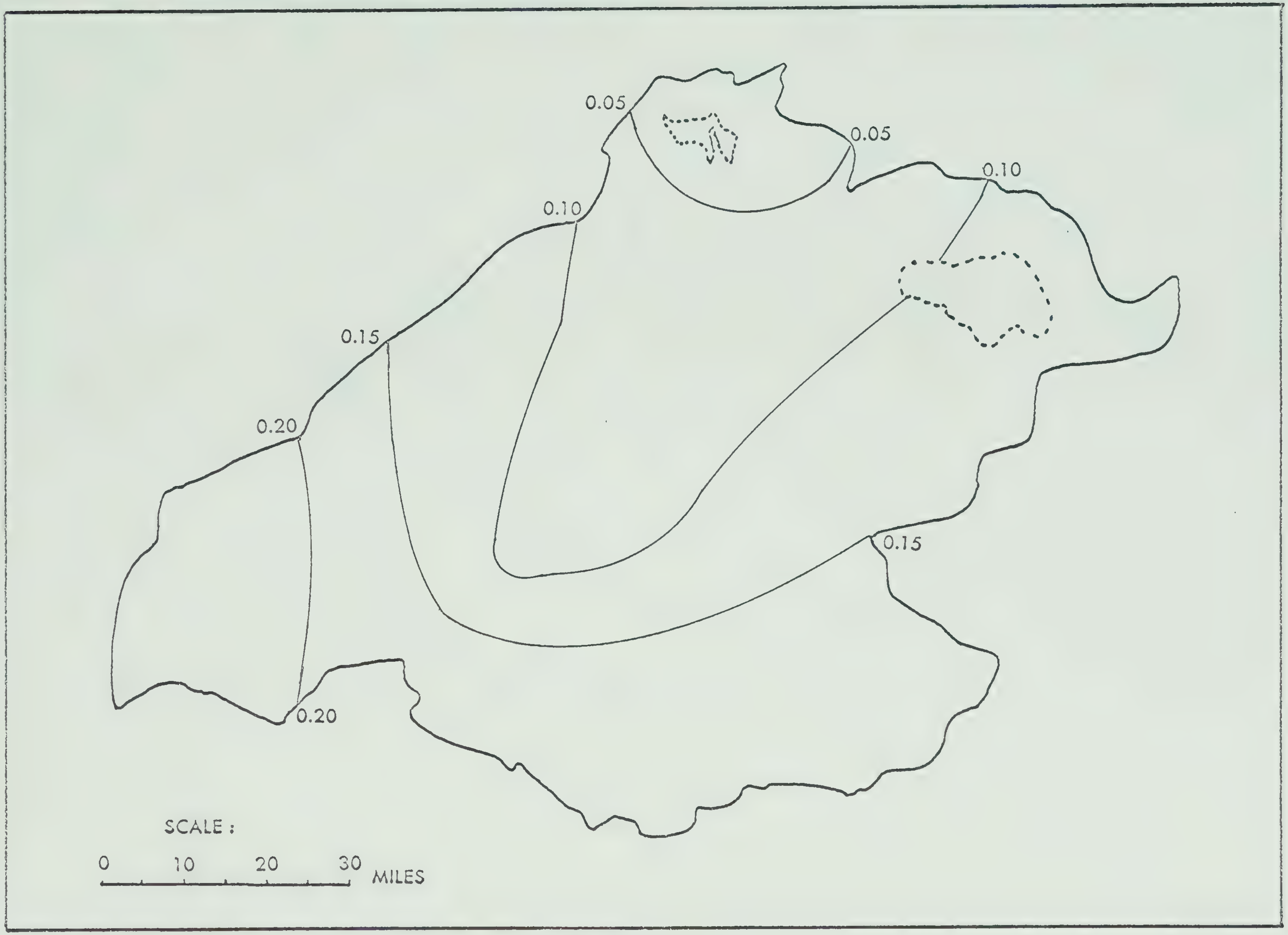


FIGURE 17

MEAN MONTHLY RUNOFF (IN INCHES) IN JUNE , JOHNSTONE LAKE BASIN, 1944-1968

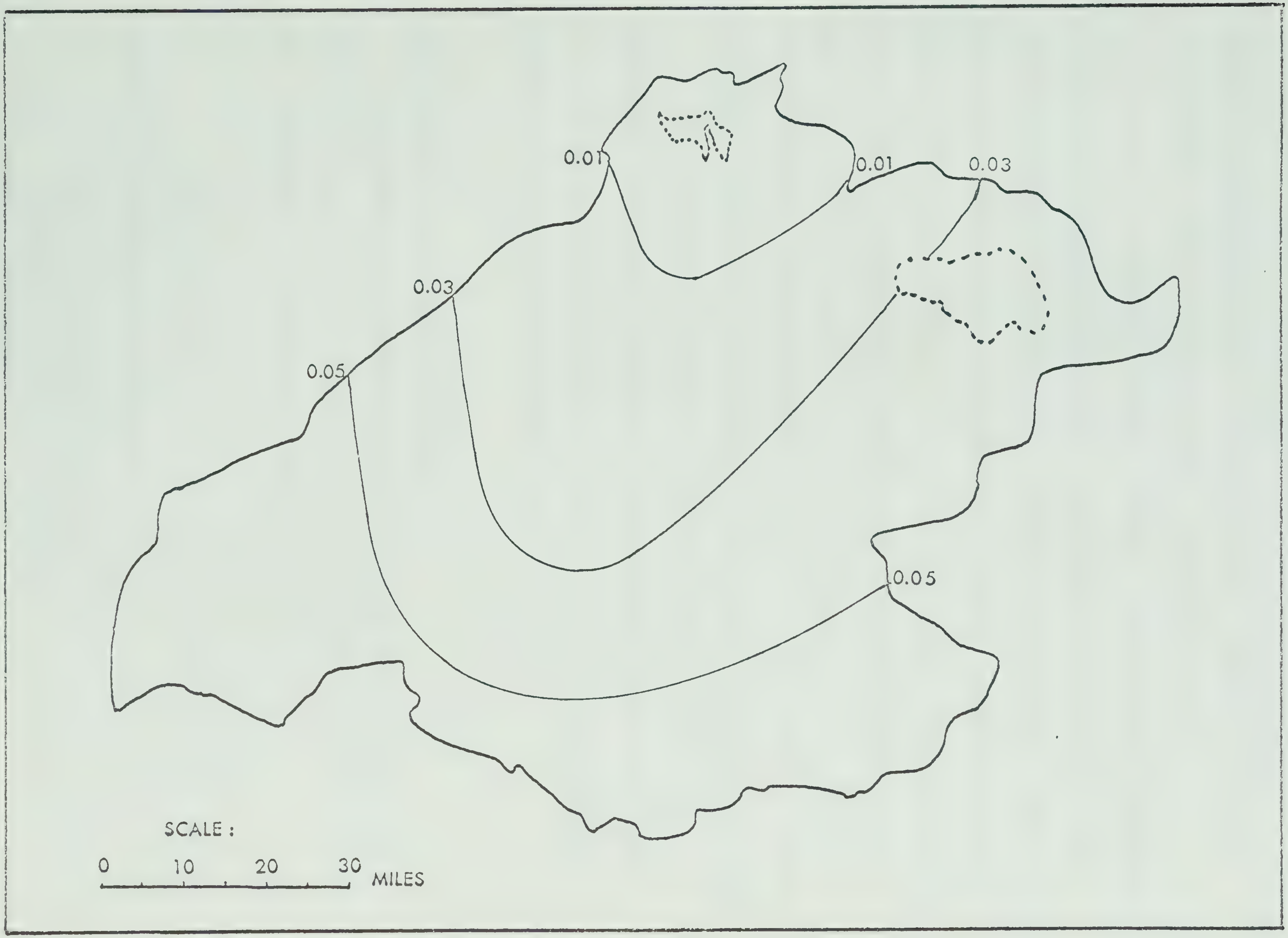


FIGURE 18

In April, the runoff reaches a peak at all stations. The relationship between computed and measured runoff is quite satisfactory, except at Notukeu Creek near Gravelbourg where streamflow losses to phreatophytes and to irrigation occur (see Chapter III).

In May, the runoff decreases rapidly in both computed and measured value, with computed runoff always being higher than measured runoff. The measured runoff, in practice, is reduced by agricultural uses and storage in reservoirs and computations do not make allowance for these. Although the same conditions occur in June, because of the compensation by the intensive runoff from rainstorms the relation between computed and measured runoff is quite close. It is obvious that the nature of the Thornthwaite procedure must fail to calculate the runoff of intensive rainstorms except when computation is being carried out on a daily basis.

Both average measured and calculated runoff of July, August, September, and October is so small that there is no significant amount of water surplus in these months. Deficits during these months have become so large that all soil moisture is depleted.

<u>The Water Balance for Johnstone Lake</u>

The hydrologic factors affecting the water balance of a closed lake are simple and well known. Assuming no groundwater flow from the lake, the balance is expressed by the equation

$$R + P (AL) = E (AL) \quad \text{----------------} \quad (2)$$

where $R =$ Runoff from drainage area

$P =$ Over water precipitation

$E =$ Evaporation rate from lake surface

$AL =$ Area of the lake.

This equation represents a long-term balance about which a lake fluctuates. These parameters will be discussed and estimated in the following paragraphs.

Runoff from the drainage area is the important contributor to the water balance of the Johnstone Lake. It is estimated that annual runoff over the effective drainage area is about 91,500 acre-feet, including those from the Wood River drainage basin, 90,950 acre-feet, and the lands surrounding Johnstone Lake, 550 acre-feet. If a water loss of 20,000 acre-feet due to a consumptive use is subtracted, the mean annual runoff to flow into Johnstone Lake is about 71,500 acre-feet. This runoff from the drainage area equals a depth of 12.20 inches for Johnstone Lake.

There are no adequate precipitation measurements over the lake. Over water, precipitation which is estimated by precipitation on land around it is about 13.50 inches.

Evaporation from a large water surface is generally inadequately measured. The calculation of evaporation from open water, while simpler in concept than that of evapotranspiration from land is equally difficult to carry out in practice. Freeze (1969a) estimated that evaporation from large lakes and reservoirs for the Johnstone Lake basin is 33 to 35 inches per year.

The gross inflow of 25.70 inches including runoff of 12.20 inches and precipitation of 13.50 inches is less than that of outflow of 34 inches evaporating from the surface of Johnstone Lake. These factors relate to the fact that Johnstone Lake is in a closed lake region. In order to quantify the degree of intermittency of a lake, Langbein(1961) used the coefficient of variation of the lake area, U, to describe the

hydrologic charater of a closed lake. The coefficient of variation of lake area is a measure of the lake's stability or degree of intermittency. From Langbein (1961):

$$U = \frac{0.156}{D} \sqrt{\frac{E\ (\ At/\ Al\ )\ k}{(\ 2 + 1/k\ )}} \quad \text{------------} \ (\ 3\ )$$

Where D = Mean depth of lake

E = Net evaporation from lake

At = Effective drainage area

Al = Area of lake

k = Response time,

the k value can explain much about the nature of fluctuations in the level of closed lakes. Langbein (1961) states that:

> "A lake with a low value of k, near 1 year, is a playa lake. It fills and dries up in a year. It responds to the current year's rainfall and virtually not at all to that of preceding years. A lake with a high value of k, on the other hand, reacts slowly and may be at a high level during a period of low rainfall and vice versa."

Freeze (1969a) estimated that the response time of Johnstone Lake is between 15 and 25 years. According to this reponse time, the coefficient of variation of lake area for Johnstone Lake is about 0.73. It is the highest value for major lakes in Saskatchewan[10]. Figure 19 shows water depths and geometric shape of Johnstone Lake on June 22, 1964. This appears at a time when the lake was exceptionally low (see Table 25).

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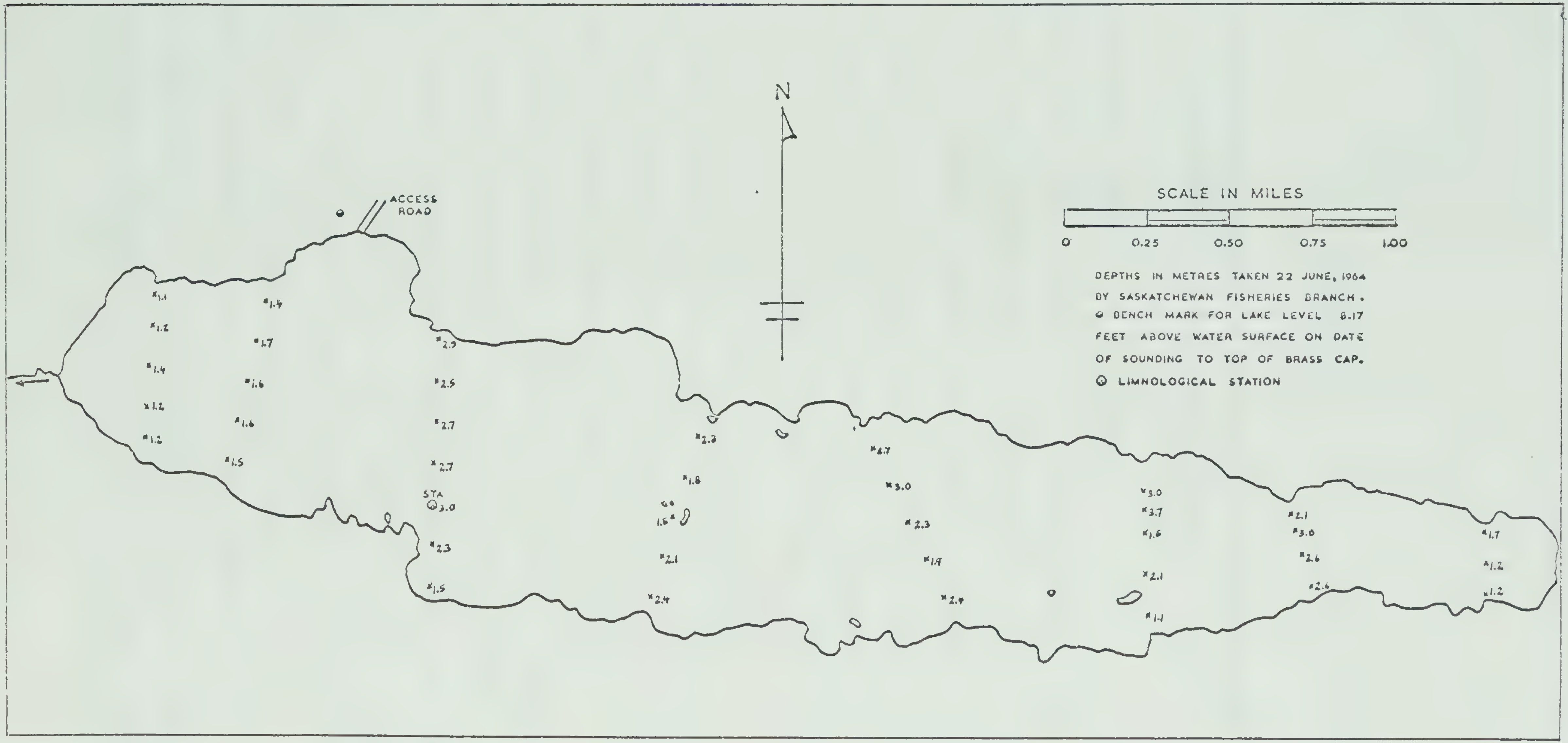
10. Coefficient of variation of lake area is 0.07 for Basin Lake in Saskatchewan, 0.15 for Quill Lake in Saskatchewan, 0.038 for Redberry Lake in Saskatchewan, 0.125 for Great Salt Lake in Utah, 1.0 for Summer Lake in Oregon, and 2.5 for Lake Eyre in Australia. See W. B. Langbein, Salinity and Hydrology of Closed Lake, U.S.G.S. Professional Paper 412, 1961, Table 1.

FIGURE 19. WATER DEPTH AND GEOMETRIC SHAPE OF JOHNSTONE LAKE, JUNE 22, 1966



CHAPTER V

THE RELATIONSHIPS BETWEEN WATER BALANCE AND DEMAND-SUPPLY PATTERNS IN THE JOHNSTONE LAKE BASIN

Climatic Water Balance and Land Use in the Basin

Irrigation is practised primarily to correct a deficit in the distribution and amount of the natural precipitation of a drainage basin. Since the need for irrigation depends upon climate, it is logical that the answer to many problems in connection with irrigation planning should be found in a study of climatic data. The use of a climatic water balance as a guide to irrigation may bring about maximum crop yields and can also keep the farmer from the dangers of over-irrigation. Variability is characteristic of stream flow as it is of weather, and because of the high variability of flow of most streams, full utilization of surface water is possible only through regulation and control.

In the Johnstone Lake basin, agriculture is the most important land use aided by some fertile soils and the comparatively higher temperature of southern Saskatchewan. Temperature is often a good index of the amount of energy available to plants from the sun. The growing degree-days in the basin are about 2,800, calculated on daily mean air temperature above 42°F. But high summer temperatures reduce by evaporation the effectiveness of relatively light rainfall. Lack of moisture for crop growing is a critical problem in the Johnstone Lake basin. Drought has been recognized as a feature of the prairie climate

since the days when Captain J. Palliser investigated the potential of the area for settlement. Thus regional resource development is dependent on availability of water supplies of useful quality in the right place and at right time. Knowledge of water surplus is important for the wise and more complete use of available water resources and for the more efficient use of land in relation to prevailing soil and climatic conditions in the Johnstone Lake basin.

In general, estimated streamflows for small basins have been used to determine the availability of water in various basins, e.g. Godwin (1961) for Wood River drainage basin, and Jansson (1968) for Russell Creek drainage basin. Such estimations may often be either inaccurate or difficult to derive (Benson and Carter, 1969). The technique of the climatic water balance is useful to estimate water availability for present use and for future development.

In the Johnstone Lake basin, an average water deficit of 9 inches is experienced annually (see Figure 9). Moisture surpluses are small, about 0.66 inch (see Figure 13), and they usually occur in early spring (see Figures 5, 6 and 7). It is apparent that irrigation is required for agricultural development in the basin, and must use this spring surplus supply which collects in local lakes and reservoirs. Except for seasonal precipitation water required for crops must come from moisture previously stored in the soil, from snowfall, fallowing, or from irrigation.

Conversion indicates that about 96,000 acre-feet of water emerge from the water yielding areas in the streams and tributaries of the Johnstone Lake basin. The wide variability in discharge during various parts of the year is a characteristic of flow for most streams in the

basin. A great part of the total runoff occurs within a relatively short period. The flows for the months of March and April in general greatly exceed the flows for other months. It is important that this runoff be conserved and managed effectively for agriculture.

Water Conservation Developments

Water conservation in the Johnstone Lake basin is largely a matter of storage and efficient use of precipitation. The most effective way to accomplish this is to catch the precipitation where it falls and hold it there for use in growing crops and raising livestock. Small water conservation projects where physiography and other conditions are favorable for the excavation of dugouts and the construction of small dams and other works are designed to store and utilize surface or runoff water on individual farms. These developments make for less inefficient use of surface water which would be lost by evaporation. Fortunately, the general physiography of the Johnstone Lake basin, e.g. numerous depressional storage potholes, is favorable to a program of small area water development. On practically every farm, wherever land with sufficient drainage area slopes toward a central or focal point in a field, suitable sites for small water storage projects can be found. Since 1935, the federal government has paid about 50 per cent of the cost of construction and has provided all agricultural and engineering services through the Prairie Farm Rehabilitation Administration. The reservoir water supplies are usually used to supplement soil moisture reserves and are applied by temporarily ponding water on relatively flat fields. Stockwatering dams and dugouts also provide domestic water for farmstead use, and some are used for supplementary irrigation of gardens

and small fields. There are some four or five thousand domestic and stockwater developments in the Johnstone Lake basin. The PFRA has paid assistance for over 2,500 dugouts and 1,600 small dams in the basin. This has been a significant contribution to agricultural development.

The major irrigation projects in the Johnstone Lake basin are shown in Table 27. Backflooding is the most popular irrigation method being used on about 80 per cent of total area irrigated. Backflooding irrigation is similar to the border method of flood irrigation. On fields that have a uniform slope in one direction, the snowmelt water can be collected from the upper area by small dams, then the water is introduced at the top end of the field and allowed to run to the bottom. Backflooding irrigation supplement for cereal crops requires about 6 to 8 inches of water. This amount compensates for the water deficit of the growing season, as calculated above. Backflooding irrigation is appropriate to cereals in the basin but not to forage crops, though it is inexpensive and simple to use. Its sources of water, however, are limited. Wheat, for instance, is the main cash crop and, according to Dubetz, Russell and Hill (1962) the increase in yields from intensive irrigation seems hardly worthwhile. As compared to most of the crops under irrigation, forage crops require large depths of irrigation water because of the large annual tonnage produced and the longer growing season required. Thus forage crops are given more intensive irrigation than cereals.

It is possible to develop more intensive irrigation in the Johnstone Lake basin, e.g. the Russell Creek Irrigation Projects. Investigations of irrigation projects by the Conservation and Development Branch of the Province of Saskatchewan and the estimates of the

TABLE 27

THE MAJOR IRRIGATION PROJECTS IN THE JOHNSTONE LAKE BASIN

Project	Water Source	Approx. Ac.	Remarks
Cadillac	Cadillac-Bull Creek Res.	100ac.	Limited irrigation, 50% forage and 50% cereal. 18" per acre.
Ponteix	Gouverneur Res. (Notukeu Creek)	1,000 ac.	80% forage, 20% cereal. 18" per acre.
Russell Creek	Russell Creek Res.	1,000 ac.	Intensive irrigation, 80% grass seed and forage, 20% cereal. 12" per acre.
	Russell Creek	1,000 ac.	Backflood irrigation, 80% cereal, 20% grass seed. 8" per acre.
Vanguard South	Notukeu Creek	1,700 ac.	Backflood irrigation, cereal crops. 8" per acre.
Wiwa Creek	Wiwa Creek	3,200 ac.	Backflood irrigation, cereal crops. 8" per acre.
Flowing Well	Tributary to the Wiwa Creek	2,500 ac.	Flood control and backflood irrigation, cereal crops. 6" per acre.
Woodrow North	Tributary to the Wood River	450 ac.	Flood control and backflood irrigation, cereal crops. 6" per acre.
Glenbain	Tributary to the Notukeu Creek	500 ac.	Flood control and backflood irrigation, cereal crops. 6" per acre.

Source: W. E. Randall, Engineer, Conservation and Development Branch, Department of Agriculture, Province of Saskatchewan, Personal letter, December 18, 1969.

Hydrological Division of PFRA indicate that future annual uses should be over 60,000 acre-feet per year. Some studies were made also on the ability of the basin to support an expanded irrigation development (Godwin, 1961 and Jansson, 1968). The six major reservoirs built by the PFRA in the Johnstone Lake basin (see Table 24) are capable of storing 41,750 acre-feet of water. At present there is only about 8,000 acre-feet used for irrigation. Consequently, specific locations and projects for new irrigation developments should be studied. A detailed comprehensive water balance study is necessary for all the small basins and the Johnstone Lake basin as a whole. It has been stated already that the accuracy of the Thornthwaite water balance method decreases if it is used for short-term calculations (see Chapter IV). Crop management operations demand more precise short-term estimates and it is impracticable to adopt the Thornthwaite method as a guide for intensive irrigation planning or operation, unless it is verified by lysimeters or by other more accurate methods for short-term calculation (Baier and Robertson, 1965; Hobbs and Krogman, 1966; Chang, 1968; Halkias, 1963; Pruit, 1960). Mather (1954) has suggested the use of maximum temperature rather than the mean temperature as the basis for calculation of PE. Maximum temperature may be closely related to the temperature of the evaporating surface. Further studies to determine the water balance of all small basins in the Johnstone Lake basin, using monthly and daily data, may aid planning and improve the agricultural water supply-demand program in the interest of the irrigation expansion which is shown here to be possible.

Summerfallow and Climatic Water Balance

One of the means of moisture conservation most widely employed

in the basin is that of summerfallow. The rotation commonly followed consists of wheat with summerfallow every second or third year. The percentage of precipitation that can be conserved by summerfallow varies from year to year, being determined by the intensity of rainfall, rate of weed growth, the soil type and by cultivation practices. Staple and Lehane (1952) in studies at Swift Current found that 1.8 inches of moisture was added to the soil in a fallow year. The average moisture content in stubble land at seeding time was 2.2 inches and that in summerfallow 4.0 inches. At the end of April, an average soil moisture retention, as previously calculated (see Tables 12, 13, 14 and Appendix I), is about 2.5 inches in the Johnstone Lake basin. Moisture levels do not reach 4 inches capacity in over half of the years studied.

Crop yield variation within the Johnstone Lake basin is much greater than for other areas of Saskatchewan. The average precipitation of 6 inches in the growing season (May 1 to July 31) is marginal for the production of wheat. Staple and Lehane (1952) showed that 5 to 6 inches of water were required, on the average, to produce a minimum yield of one or two bushels per acre. With more available water the production efficiency increased slowly until 10.5 inches of water produced a mean yield of 14 bushels per acre. For higher incomes of soil water potential from precipitation or irrigation the increase in yield with each additional inch of water was almost constant at 6 bushels per acre. In wet years, the stored moisture added to seasonal precipitation is usually over 10.5 inches in the Johnstone Lake basin, then the availability of an additional 1.5 inches of moisture conserved by summerfallow could increase yields by about 10 bushels per acre. Thus summerfallowing is a useful method for conserving moisture in the basin.

Many experiments have emphasized that there is a high correlation between the stored moisture in the soil at seeding time and the resultant crop yields, e.g. Cole and Mathews (1940) in the Great Plains, Finnel (1949) in Texas, Staple (1954) and Janzen et al (1960) at Swift Current. In the present study, the multiple correlation coefficient between wheat yield, Y, and seasonal precipitation, P, and stored moisture, S, at the end of April was 0.77 at Gravelbourg and the linear multiple regression equation was

$$Y = 3.21\,P + 1.92\,S - 8.78 \qquad \text{----------------} \quad (4)$$

The analysis of this multiple regression is shown in Table 28.

TABLE 28: MULTIPLE REGRESSION ANALYSIS BETWEEN WHEAT YIELD, AND SEASONAL PRECIPITATION AND STORED MOISTURE AT GRAVELBOURG.

Source of Variation	df	Sum of Squares	Mean Square	F	1 Percent Level
Regression	2	1092.16	546.08	17.18	5.66
Error	23	731.22	31.79		
Total	25	1823.38			

Moisture stored at seeding time is therefore a very important factor for higher yields in the basin. Since seasonal precipitation in the Johnstone Lake basin is the absolute minimum required for crop production there, it is seldom that sufficient precipitation is received

during the growing season to overcome a soil moisture storage level below the 2.5 inches mean at seeding time in late or early spring.

The calculation of soil moisture retention from the method of the climatic water balance is helpful to obtain the water content of soil at seeding time (see Chapter II). The chances of seeding a crop with a high expectation of failure or unsatisfactory yield may be materially reduced, and advantage may be taken of favorable indications to seed normal or above normal acreages in this basin.

In the present study, the techniques used are exploratory ones, which suggest levels of magnitude of available water for future development of the basin. The analysis has shown that the patterns of precipitation distribution in the basin make the region dependent on the snowmelt runoff, which must be stored in reservoirs for summer use. Reservoirs often alienate land useful for development, though this is not a serious problem in the Johnstone Lake basin. A more serious problem is caused by the nature of required reservoirs for the small sub-basins in the Johnstone Lake basin. Reservoirs required for these sub-basins would tend to be relatively shallow and wide. As a result, evaporation rates are increased. However, methods of evaporation reduction, such as surface-area reduction and mechanical and chemical covers, must be practised to diminish the evaporation rate from these reservoirs.

In the final analysis, it seems that present agricultural land use practices can be continued in this enclosed and climatically precarious drainage basin, provided that the efficiency of storage conservation and the use of already limited water supply is improved.

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APPENDIX I

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS, APRIL TO OCTOBER.

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR ANEROID

2 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1923	1.77	0	2.00	0.01	0	0	0
1924	1.51	0.32	0.96	0	0	0	0.19
1925	2.00	0.33	0	0	0	0.55	2.00
1926	0.62	0	0.67	0	0	0	0
1927	1.79	2.00	0.31	0	0	0	0
1928	2.00	0	0.96	0	0	0	0
1929	1.60	0.01	0	0	0	0	0
1930	1.55	0	0	0	0	0.01	0.13
1931	0.11	0	0	0	0	0	0
1932	0.94	0	0	0	0	0	0.17
1933	1.59	1.12	0	0	0	0	0.35
1934	0.27	0	0.50	0	0	0.67	0
1935	2.00	1.19	0.77	0	0	0	0
1936	1.89	0	0	0	0	0	0
1937	1.37	0	0	0	0	0	0
1938	1.03	1.91	0.14	0	0	0	0
1939	1.15	1.63	2.00	0	0	0	0.34
1940	2.00	0	0	0	0	0	0
1941	1.29	0	0	0	0	0	0
1942	2.00	0.43	1.88	0	0	0	0
1943	0.44	0.26	0	0	0	0	0.74
1944	0.74	0	0	0	0	0	0
1945	2.00	0.31	0	0	0	0	0
1946	0	0	0	0	0	0	0.21
1947	2.00	0.86	0	0	0	0	0
1948	2.00	0.24	0	0	0	0	0
1949	0	0	0	0	0	0	0.78
1950	1.75	0	0	0	0	0	0
1951	1.65	0	0.59	0	0	0	0.16
1952	0	0	0	0	0	0	0
1953	2.00	2.00	0.91	0	0	0	0
1954	2.00	1.45	1.26	0	0	0	0
1955	2.00	1.92	0	0.36	0	0	0
1956	0.87	0	0	0	0	0	0
1957	2.00	0	0	0	0	0	0.20
1958	2.00	0	0	0	0	0	0
1959	1.64	0	0	0	0	0	0.35
1960	0.74	0	0	0	0	0	0
1961	2.00	0.77	0	0	0	0	0.22
1962	0.67	0	0	0	0	0	0
1963	0.89	0	0.41	0	0	0	0
1964	1.12	0	0	0	0	0	0
1965	1.52	1.10	0.09	0	0	0.74	0
1966	2.00	0	0.33	0	0	0	0
1967	2.00	0.18	0	0	0	0.40	0.25
1968	0.58	0	0	0	0	0	0

MOISTURE RETAINED IN THE SOIL AT END OF THE MONTHS FOR ANEROID

6 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1923	1.77	0	4.84	2.85	0	0	0
1924	1.51	0.32	0.96	0	0	0	0.19
1925	4.98	3.31	1.47	0	0	0.55	2.33
1926	3.67	1.91	2.58	0	0	0	0
1927	3.11	6.00	4.31	1.01	0	0	0
1928	2.25	0	0.96	0	0	0	0
1929	2.15	0.56	0	0	0	0	0
1930	2.63	0.12	0	0	0	0	0.13
1931	0.11	0	0	0	0	0	0
1932	1.76	0	0	0	0	0	0.17
1933	1.59	1.12	0	0	0	0	0.35
1934	1.85	0	0.50	0	0	0	0
1935	2.34	1.53	1.11	0	0	0	0
1936	2.38	0.05	0	0	0	0	0
1937	1.47	0	0	0	0	0	0
1938	3.34	4.22	2.45	0	0	0	0
1939	1.65	2.13	4.43	0.20	0	0	0.34
1940	6.00	3.44	3.32	0.76	0	0	0
1941	2.16	0	0	0	0	0	0
1942	4.61	3.04	4.49	1.89	0	0	0.27
1943	2.81	2.63	1.71	0	0	0	0.74
1944	0.89	0	0	0	0	0	0
1945	3.92	2.23	0.74	0	0	0	0
1946	0.62	0	0	0	0	0	0.21
1947	3.99	2.85	1.40	0	0	0	0
1948	4.19	2.43	0	0	0	0	0
1949	0.27	0	0	0	0	0	0.78
1950	4.49	2.38	0	0	0	0	0
1951	5.00	1.62	2.21	0	0	0	0.16
1952	3.93	1.81	0.01	0	0	0	0
1953	6.00	6.00	4.91	0.49	0	0	0
1954	6.00	5.45	5.26	1.59	0	0	0.02
1955	2.63	2.55	0	0.36	0	0	0
1956	0.87	0	0	0	0	0	0
1957	2.06	0	0	0	0	0	0.20
1958	2.51	0	0	0	0	0	0
1959	1.64	0	0	0	0	0	0.35
1960	0.74	0	0	0	0	0	0
1961	3.25	2.02	0	0	0	0	0.22
1962	3.04	1.27	0.08	0	0	0	0
1963	0.89	0	0.41	0	0	0	0
1964	1.75	0	0	0	0	0	0
1965	4.09	3.67	2.66	0.31	0	0	0
1966	4.87	2.47	2.80	0	0	0	0
1967	6.00	4.18	1.30	0	0	0	0.25
1968	1.01	1.01	0	0	0	0	0

MOISTURE RETAINED IN THE SOIL AT END OF THE MONTHS FOR CHAPLIN

2 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1921	1.69	0.28	0	0	0	2.00	1.83
1922	1.88	1.67	0	0	0	0	0
1923	1.68	0.50	0	0	0	0	0
1924	2.00	0.65	1.36	0	0	0	0.41
1925	1.52	0	0	0	0	0	0.23
1926	0.97	0.30	0	0	0	0.19	0
1927	1.74	2.00	0	0	0	0	0.13
1928	2.00	0	2.00	0	0	0	0.03
1929	1.86	0.98	0	0	0	0	0
1930	1.65	0	0	0	0	0	1.12
1931	0.59	0	0	0	0	0	0
1932	1.38	0	0	0	0	0	1.37
1933	2.00	1.13	0	0	0	0	0
1934	1.05	0	0.78	0	0	0	0
1935	1.55	1.23	0.66	0	0	0	0
1936	1.71	0.39	0	0	0	0	0
1937	0.94	0	0	0	0	0	0
1938	1.74	1.15	0	0	0	0	0
1939	1.02	0	1.09	0	0	0	0.25
1940	2.00	0	0	0	0	0	0
1941	1.07	0	0	0	0	0	0
1942	2.00	0	1.59	0	0	0	0
1943	0.56	1.10	0	0	0	0	0.78
1944	1.26	0.85	0.16	0	0	0	0.01
1945	2.00	0.24	0	0	0	0.35	0.25
1946	0.56	0	0	0	0	0	0.70
1947	2.00	0.35	1.49	0	0	0	0
1948	2.00	0	0	0	0	0	0
1949	0	0	0	0	0	0	0.94
1950	2.00	0.57	0	0	0	0	0
1951	2.00	0	1.25	0	0.34	0.33	0.39
1952	0	0	0	0	0	0	0
1953	2.00	2.00	2.00	0	0	0	0
1954	1.63	1.25	0	0	0.48	0	0
1955	2.00	1.93	0	0	0	0	0.92
1956	2.00	0.06	0	0	0	0	0
1957	2.00	0	0	0	0	0	0.34
1958	1.28	0	0	0	0	0	0
1959	1.20	0	0	0	0	1.57	2.00
1960	1.61	0	0.64	0	0	0	0
1961	2.00	0.05	0	0	0	0	0.26
1962	0.30	0	0	0	1.01	0	0
1963	0.70	0.21	2.00	0	0	0	0
1964	1.23	0	0	0	0	0	0
1965	1.74	2.00	0.29	0	0	0.65	0
1966	2.00	0	0	0	0	0	0

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR CHAPLIN

6 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1921	1.70	0.29	0	0	0	2.18	2.01
1922	4.01	3.80	0	0	0	0	0
1923	1.78	0.60	0.04	0	0	0	0
1924	4.68	3.33	4.04	0.80	0	0	0.41
1925	2.18	0.43	0	0	0	0	0.23
1926	1.00	0.33	0	0	0	0.19	0
1927	4.86	6.00	2.60	0	0	0	0.13
1928	2.36	0	2.03	0	0	0	0.03
1929	1.86	0.98	0	0	0	0	0
1930	2.63	0.81	0	0	0	0	1.12
1931	0.59	0	0	0	0	0	0
1932	1.59	0	0	0	0	0	1.37
1933	2.27	1.40	0	0	0	0	0
1934	2.07	0	0.78	0	0	0	0
1935	2.40	2.08	1.51	0	0	0	0
1936	4.34	3.02	0.56	0	0	0	0
1937	1.09	0	0	0	0	0	0
1938	3.26	2.67	0	0	0	0	0
1939	2.49	0.51	1.60	0	0	0	0.25
1940	3.73	1.10	0	0	0	0	0
1941	2.66	0.71	0	0	0	0	0
1942	4.51	2.40	3.99	0	0	0	0
1943	2.94	3.48	0.77	0	0	0	0.78
1944	2.53	2.12	1.43	0	0	0	0
1945	3.16	1.40	0	0	0	0.35	0.25
1946	1.53	0	0	0	0	0	0.70
1947	4.46	2.81	3.95	0	0	0	0
1948	4.33	1.51	0	0	0	0	0
1949	0	0	0	0	0	0	0.94
1950	3.86	2.43	0	0	0	0	0
1951	3.15	0	1.25	0	0.34	0	0.39
1952	0.60	0	0	0	0	0	0
1953	3.19	3.55	4.15	0	0	0	0
1954	1.63	1.25	0	0	0.48	0.61	0
1955	2.12	2.05	0	0	0	0	0.92
1956	3.56	1.62	0	0	0	0	0
1957	2.15	0	0	0	0	0	0.34
1958	3.11	0	0	0	0	0	0
1959	1.42	0	0	0	0	1.57	2.64
1960	4.24	2.55	3.19	0	0	0	0
1961	3.11	1.16	0	0	0	0	0.26
1962	2.29	0.69	0	0	1.01	0	0
1963	0.70	0.21	3.24	0	0	0	0
1964	1.42	0	0	0	0	0	0
1965	5.23	5.51	3.80	0	0	0.65	0
1966	6.00	3.32	2.08	0	0	0	0

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR GRAVELBOURG

2 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1928	1.08	0	0	0	0	0	0
1929	1.13	0	0	0	0	0	0
1930	1.63	0	0	0	0	0	0.67
1931	0.62	0	0	0	0	0	0
1932	1.22	0	0	0	0.71	0	0.35
1933	1.57	1.28	0.21	0	0	0	0.25
1934	0.71	0	0	0	0	0	0
1935	1.73	2.00	0	0	0	0	0
1936	2.00	0.71	0	0	0	0	0
1937	1.39	0	0	0	0	0	0
1938	1.18	0.01	0	0	0	0	0
1939	0.89	0	2.00	0	0	0	0
1940	2.00	0	0	0	0	0	0
1941	1.67	0.49	0	0	0	0	0
1942	2.00	0.79	1.77	0	0	0	0
1943	0.47	0.74	0	0	0	0	0
1944	0.69	1.45	0.07	0	0	0	0
1945	2.00	0	0	0	0	0	0
1946	0	0	0	0	0	0	0.43
1947	1.12	0	0.29	0	0	0	0
1948	2.00	0	0	0	0	0	0
1949	0	0	0	0	0	0	0.22
1950	2.00	0.33	1.13	0	0	0	0
1951	2.00	0	0.47	0	0.42	0	0.53
1952	0	0	0	0	0	0	0
1953	2.00	2.00	0.70	0	0	0	0
1954	2.00	1.92	1.58	0	0.82	1.36	0.40
1955	2.00	2.00	0	0	0	0	0
1956	1.70	0.14	0	0	0	0	0
1957	2.00	0	0	0	0	0	0.27
1958	1.42	0	0	0	0	0	0
1959	2.00	0.01	0	0	0	0	0.71
1960	1.83	0.04	1.59	0	0	0	0
1961	2.00	0.51	0	0	0	0	0
1962	0	0	0	0	0	0	0
1963	2.00	0.38	2.00	0	0	0	0
1964	1.08	0	0	0	0	0	0
1965	1.52	1.01	0	0	0	1.15	0
1966	2.00	0.08	0	0	0	0	0
1967	2.00	0	0	0	0	0.04	0.32
1968	0.42	0	0	0	0	0	0

MOISTURE RETAINED IN THE SOIL AT THE END OF THE MONTHS FOR GRAVELBOURG

6 inch Moisture Holding Capacity of Soil

Year	April	May	June	July	Aug.	Sept.	Oct.
			(in inches)				
1928	1.08	0	0	0	0	0	0
1929	1.97	0	0	0	0	0	0
1930	5.39	3.45	1.30	0	0	0	0.67
1931	1.19	0	0	0	0	0	0
1932	3.91	1.00	0	0	0.71	0	0.35
1933	2.42	2.13	0	0	0	0	0.25
1934	2.11	0	0.21	0	0	0	0
1935	3.33	4.81	2.77	0	0	0	0
1936	4.51	3.22	0.12	0	0	0	0
1937	1.59	0	0	0	0	0	0
1938	4.04	2.87	0.50	0	0	0	0
1939	1.88	0.72	2.80	0	0	0	0
1940	3.68	1.08	0.11	0	0	0	0
1941	2.64	1.46	0	0	0	0	0
1942	5.46	4.25	5.23	1.50	0.38	0	0
1943	3.39	3.66	1.97	0	0	0	0
1944	0.69	1.45	0.07	0	0	0	0
1945	5.61	3.42	1.40	0	0	0	0
1946	0	0	0	0	0	0	0.43
1947	3.50	2.28	2.57	0	0	0	0
1948	4.10	1.07	0	0	0	0	0
1949	1.98	0	0	0	0	0	0.22
1950	5.25	3.58	4.38	1.72	0	0	0
1951	6.00	2.63	3.10	0	0.42	0	0.53
1952	2.71	0.74	0	0	0	0	0
1953	4.14	5.52	4.22	0	0	0	0
1954	3.88	3.80	3.46	0	0.82	1.36	0.40
1955	2.95	4.20	0.91	0	0	0	0
1956	2.28	0.72	0	0	0	0	0
1957	3.06	0	0	0	0	0	0.27
1958	2.79	0	0	0	0	0	0
1959	1.12	0.84	0	0	0	0.71	1.02
1960	2.93	1.14	2.69	0	0	0	0
1961	3.05	1.56	0	0	0	0	0
1962	0.27	0	0	0	0	0	0
1963	2.42	0.80	2.86	0.06	0	0	0
1964	1.64	0	0	0	0	0	0
1965	3.39	2.88	1.46	0	0	1.15	0
1966	3.87	1.95	0	0	0	0	0
1967	4.75	2.37	0	0	0	0.04	0.32
1968	1.37	0	0	0	0	0	0

APPENDIX II

CLIMATIC WATER BALANCE

CLIMATIC WATER BALANCE FOR CADILLAC 1941-1959

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	-	Deficit)	+	Surplus	±	St.Change
			(in inches)						
1941	14.55	=	(22.45	-	7.90)	+	0	+	0
1942	17.92	=	(21.73	-	3.74)	+	0	-	0.07
1943	13.16	=	(22.17	-	8.44)	+	0.10	-	0.67
1944	11.80	=	(22.22	-	9.90)	+	0	-	0.52
1945	13.04	=	(20.65	-	8.69)	+	0	+	1.08
1946	10.58	=	(22.12	-	12.16)	+	0	+	0.62
1947	12.99	=	(21.24	-	6.97)	+	0	-	1.28
1948	13.34	=	(22.55	-	10.67)	+	0.76	+	0.70
1949	8.41	=	(23.61	-	14.46)	+	0	-	0.74
1950	16.05	=	(21.34	-	5.98)	+	0.52	+	0.17
1951	18.48	=	(20.22	-	3.97)	+	2.22	+	0.01
1952	16.26	=	(21.95	-	4.73)	+	0	-	0.96
1953	16.29	=	(22.58	-	9.01)	+	2.47	+	0.25
1954	19.91	=	(20.49	-	1.64)	+	1.46	-	0.40
1955	17.29	=	(22.11	-	6.52)	+	0	+	1.70
1956	12.50	=	(21.45	-	7.95)	+	0	-	1.00
1957	9.09	=	(21.97	-	12.71)	+	0	-	0.17
1958	9.92	=	(21.96	-	12.69)	+	0	+	0.65
1959	7.13	=	(21.59	-	13.33)	+	0	-	1.13
Average	13.99	=	(21.83	-	8.50)	+	0.78	-	0.12

CLIMATIC WATER BALANCE FOR HODGEVILLE 1956-1968

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	- Deficit)	+	Surplus	±	St. Change
			(in inches)					
1956	11.26	=	(21.20	- 9.94)	+	0	+	0
1957	9.56	=	(21.96	- 12.53)	+	0	+	0.13
1958	8.98	=	(22.09	- 13.79)	+	0	+	0.68
1959	13.23	=	(21.19	- 8.42)	+	0	+	0.46
1960	12.01	=	(22.90	- 10.78)	+	0	-	0.11
1961	11.77	=	(22.15	- 9.32)	+	0.17	-	1.23
1962	15.09	=	(22.09	- 6.48)	+	0	-	0.52
1963	15.63	=	(22.19	- 6.64)	+	0	+	0.08
1964	13.28	=	(22.14	- 10.55)	+	0	+	1.69
1965	19.99	=	(21.41	- 1.22)	+	0.22	-	0.42
1966	14.79	=	(21.37	- 8.13)	+	1.91	-	0.36
1967	12.54	=	(20.56	- 10.64)	+	2.78	-	0.16
1968	8.94	=	(22.68	- 13.73)	+	0	-	0.01
Average	12.85	=	(21.84	- 9.39)	+	0.45	-	0.05

CLIMATIC WATER BALANCE FOR INSTOW 1954-1968

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	-	Deficit)	+	Surplus	±	St. Change
					(in inches)				
1954	23.19	=	(19.32	-	1.50)	+	4.94	+	0.43
1955	22.04	=	(20.20	-	3.07)	+	2.54	+	2.37
1956	14.89	=	(19.61	-	6.57)	+	2.18	-	0.33
1957	13.36	=	(20.87	-	10.15)	+	2.65	-	0.01
1958	9.91	=	(21.99	-	12.49)	+	1.41	-	1.00
1959	12.32	=	(21.12	-	8.30)	+	0	-	0.50
1960	12.12	=	(22.80	-	10.88)	+	0	+	0.20
1961	8.37	=	(21.71	-	13.94)	+	0	+	0.60
1962	19.16	=	(23.14	-	3.57)	+	0.92	-	1.33
1963	14.51	=	(22.36	-	8.65)	+	0	+	0.80
1964	13.54	=	(21.73	-	8.65)	+	0	+	0.46
1965	22.43	=	(19.52	-	0)	+	0.64	+	2.27
1966	18.47	=	(21.37	-	6.35)	+	5.74	-	2.29
1967	17.89	=	(20.56	-	12.52)	+	9.04	+	0.81
1968	12.34	=	(21.12	-	8.88)	+	0	+	0.10
Average	15.63	=	(21.16	-	7.70)	+	2.00	+	0.17

CLIMATIC WATER BALANCE FOR PAMBRUN 1957-1968

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	-	Deficit)	+	Surplus	$\pm$	St. Change
			(in inches)						
1957	12.87	=	(21.21	-	9.45)	+	1.11	+	0
1958	12.61	=	(22.87	-	10.08)	+	0	-	0.18
1959	11.36	=	(21.16	-	10.73)	+	0	+	0.93
1960	13.75	=	(22.12	-	7.42)	+	0	-	0.95
1961	8.51	=	(22.04	-	13.39)	+	0	-	0.14
1962	11.91	=	(22.46	-	9.50)	+	0	-	1.05
1963	12.23	=	(23.16	-	11.27)	+	0	+	0.34
1964	11.82	=	(23.60	-	12.93)	+	0	+	1.15
1965	22.12	=	(21.06	-	0)	+	0.16	+	0.90
1966	11.74	=	(21.37	-	9.57)	+	1.50	-	1.56
1967	15.24	=	(20.56	-	10.27)	+	3.79	+	1.16
1968	9.62	=	(21.93	-	10.86)	+	0	-	1.45
Average	12.82	=	(21.96	-	9.62)	+	0.55	-	0.07

CLIMATIC WATER BALANCE FOR SHAMROCK 1957-1968

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	-	Deficit)	+	Surplus	±	St. Change
			(in inches)						
1957	9.38	=	(21.96	-	13.61)	+	0	+	1.03
1958	11.64	=	(22.37	-	11.24)	+	0	+	0.51
1959	13.25	=	(20.54	-	7.59)	+	0	+	0.30
1960	13.32	=	(22.52	-	8.52)	+	0.29	-	0.97
1961	10.13	=	(22.15	-	13.14)	+	0.44	+	0.68
1962	17.83	=	(22.46	-	4.22)	+	1.12	-	1.53
1963	20.24	=	(22.46	-	3.58)	+	0.76	+	0.60
1964	11.40	=	(22.42	-	12.39)	+	0	+	1.37
1965	19.02	=	(21.47	-	4.95)	+	2.52	-	0.02
1966	14.46	=	(21.37	-	7.88)	+	1.80	-	0.83
1967	14.61	=	(21.69	-	10.80)	+	3.45	+	0.27
1968	10.58	=	(22.27	-	11.00)	+	0	-	0.69
Average	13.82	=	(21.97	-	9.07)	+	0.86	+	0.06

CLIMATIC WATER BALANCE FOR SHAUNAVON 1951-1968

4 inch Moisture Holding Capacity of Soil

Year	Ppt.	=	(PE	- Deficit)	+ Surplus	± St. Change
			(in inches)			
1951	19.09	=	(20.20	- 2.19)	+ 1.08	+ 0
1952	16.22	=	(22.23	- 5.70)	+ 0	- 0.30
1953	15.12	=	(21.33	- 7.78)	+ 1.78	- 0.22
1954	19.41	=	(20.50	- 1.75)	+ 0	+ 0.66
1955	17.28	=	(21.64	- 4.91)	+ 0.63	- 0.08
1956	12.00	=	(21.39	- 9.74)	+ 0	+ 0.35
1957	10.65	=	(21.59	- 11.20)	+ 0	+ 0.26
1958	10.55	=	(21.97	- 11.69)	+ 0	+ 0.27
1959	13.56	=	(20.82	- 6.63)	+ 0	- 0.63
1960	12.81	=	(21.99	- 9.49)	+ 0	+ 0.31
1961	8.71	=	(22.66	- 13.32)	+ 0	- 0.63
1962	18.85	=	(22.66	- 4.11)	+ 0.89	- 0.59
1963	12.83	=	(23.09	- 11.07)	+ 0	+ 0.81
1964	17.23	=	(22.01	- 6.92)	+ 0.56	+ 1.58
1965	22.21	=	(20.60	- 0.37)	+ 1.24	+ 0.74
1966	15.67	=	(21.37	- 6.38)	+ 2.27	- 1.59
1967	14.18	=	(20.46	- 11.88)	+ 5.84	- 0.24
1968	11.24	=	(22.27	- 11.14)	+ 0	+ 0.11
Average	14.87	=	(21.60	- 7.57)	+ 0.79	+ 0.05

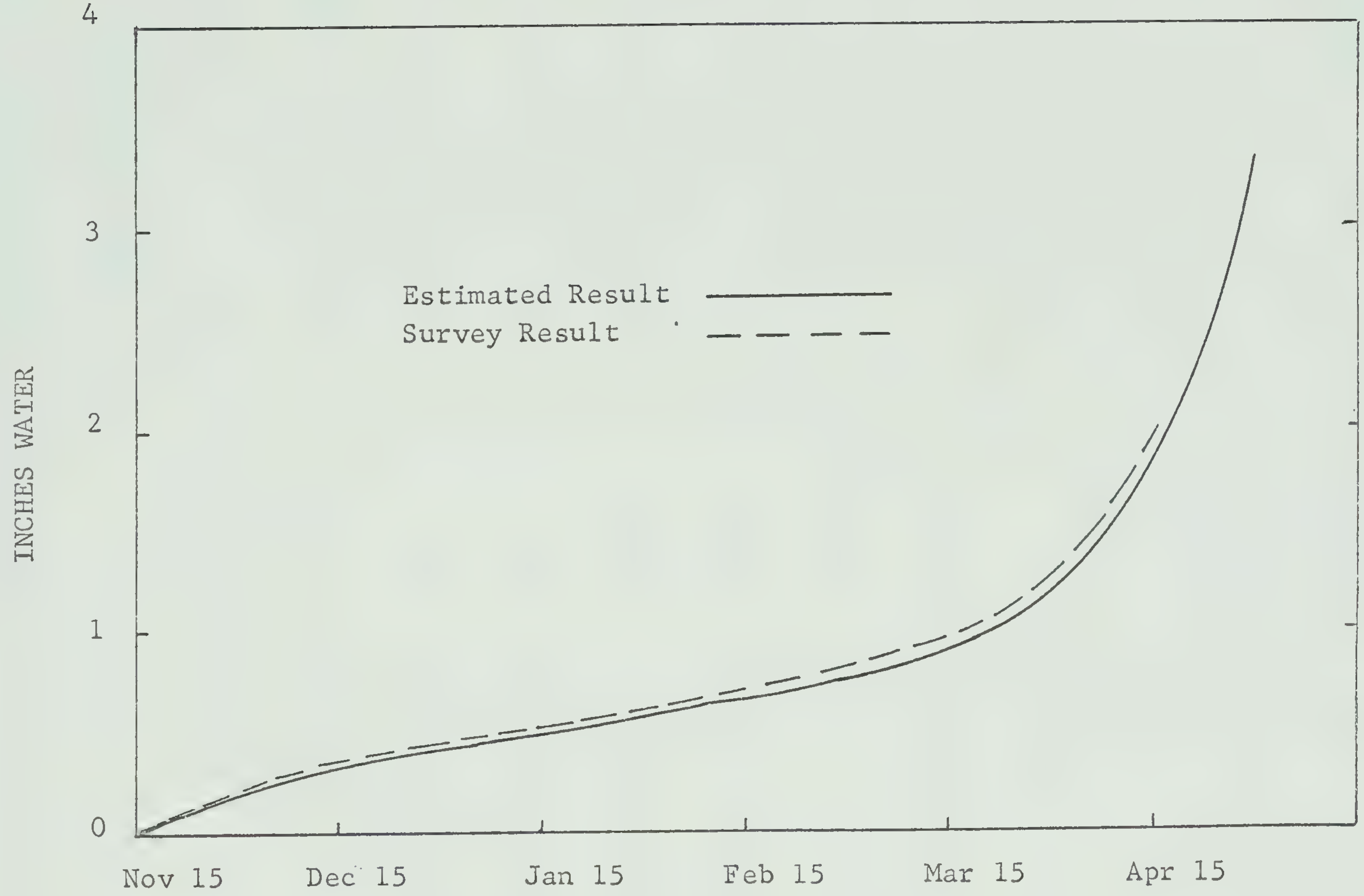
APPENDIX III

SNOW SEASON EVAPORATION

PE FOR THE MONTHS WITH MEAN TEMPERATURE BELOW 32°F., SWIFT CURRENT, SASKATCHEWAN

Year	Jan.	Feb.	Mar.	-- Nov.	Dec.	Total
			(in inches)			
1921	0.08	0.34	0.45	0.28	0.18	1.33
1922	0.05	0	0.26	0.36	0.11	0.78
1923	0.05	0.06	0.23		0.25	0.59
1924	0.08	0.29	0.12	0.20	0.05	0.74
1925	0.06	0.09	0.34	0.34	0.22	1.05
1926	0.06	0.17	0.52	0.27	0.05	1.07
1927	0.06	0.06	0.35	0.11	0.01	0.59
1928	0.13	0.17	0.74		0.19	1.23
1929	0.02	0		0.31	0.15	0.48
1930	0	0.37	0.50	0.46	0.22	1.55
1931	0.37	0.53	0.55	0.40	0.16	2.01
1932	0.04	0.22	0.22	0.25	0.07	0.80
1933	0.08	0.10	0.68	0.39	0.12	1.37
1934	0.19	0.35	0.48	0.60	0.06	1.68
1935	0.08	0.23	0.31	0.11	0.15	0.88
1936	0	0.01	0.24	0.55	0.11	0.91
1937	0	0.03	0.33	0.31	0.09	0.76
1938	0.05	0.08	0.54	0.20	0.14	1.01
1939	0.04	0.03	0.57		0.44	1.08
1940	0.04	0.02	0.18	0.07	0.15	0.46
1941	0.13	0.15	0.40	0.37	0.20	1.25
1942	0.27	0	0.41	0.19	0.09	0.96
1943	0.04	0.09	0.24	0.19	0.16	0.72
1944	0.18	0.01	0.14	0.21	0.06	0.60
1945	0.04	0.04	0.73	0.12	0.08	1.01
1946	0.02	0.07		0.28	0.06	0.43
1947	0.08	0.07	0.15	0.14	0.10	0.54
1948	0.04	0.01	0.12	0.21	0.02	0.40
1949	0.04	0.05	0.36		0.04	0.49
1950	0	0.05	0.10	0.22	0.05	0.42
1951	0	0.02	0.06	0.13	0.05	0.26
1952	0.02	0.03	0.06	0.34	0.10	0.55
1953	0.08	0.04	0.28	0.11	0.13	0.64
1954	0.05	0.37	0.13		0.20	0.75
1955	0.02	0.03	0.16	0.13	0.04	0.38
1956	0.01	0.01	0.24	0.28	0.16	0.70
Mean	0.07	0.12			0.12	0.85

Source: Prairie Provinces Water Board, Study of the Aridity of the Prairies, Daily Tabulation 1921-1956 for Swift Current, Saskatchewan.



ACCUMULATED SNOW SEASON EVAPORATION FOR REGINA after McKay (1962)

APPENDIX IV

HYDROLOGICAL RECORDS IN THE JOHNSTONE LAKE BASIN

Station No.	Name	Drainage Area (Sq.Mi.)	Gauge Location ° ' "	Discharge Records (1914-1968)
05JD002	Old Wives Lake near Old Wives		50 09 39 106 00 30	36*
05JD001	Old Wives Lake near Old Wives		50 00 30 105 49 30	18-30*
05JA002	Wood River near La Fleche	2,000	49 40 05 106 41 35	44-56** 57-68***
05JA001	Wood River near Gravelbourg	2,150	49 50 106 33	17-25,35-36,40**
05JB001	Notukeu Creek near Vanguard	1,420	49 53 45 107 18 05	14-23,40,44-64** 65-68***
05JB003	Notukeu Creek near Gravelbourg	1,900	49 55 45 106 33 00	23-25,35-36,40, 44-68**
05JB002	Rusell Creek near Vanguard	120	49 54 15 107 22 20	44-64** 65-68***
05JC001	Wiwa Creek near Gravelbourg	600	50 02 14 106 32 58	21-25,36** 66-68***
05JC002	Chaplin Lake near Chaplin		50 27 107 22 20	35-36*

Note: * Water level only.
** Manual gauge.
*** Recording gauge.

Source: Canada-Department of Energy, Mines & Resources-Inland Waters Branch, Surface Water Data Reference Index: Saskatchewan, 1968 Ottawa, 1969, p. 33.

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